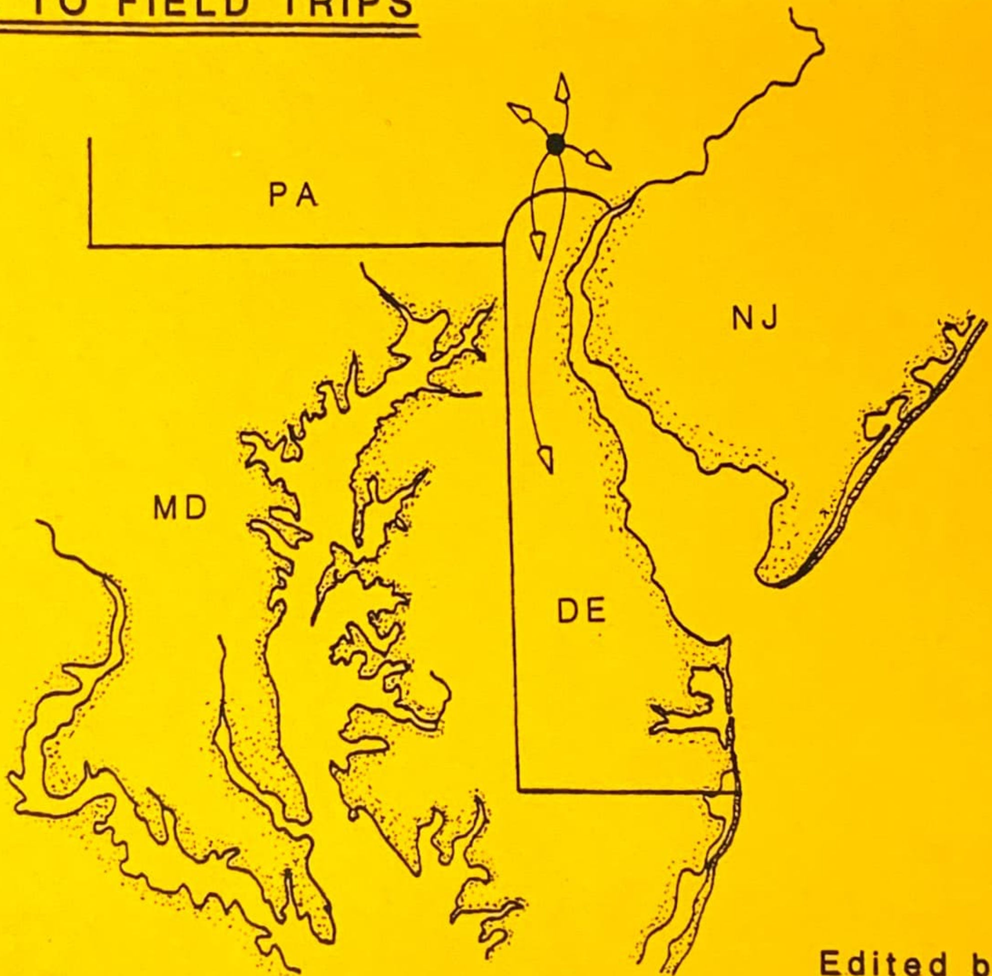
NAGT

West Chester University

GUIDE TO FIELD TRIPS



Edited by
C. Gil Wiswall
Charles H. Fletcher III

1988 EASTERN SECTION ANNUAL MEETING

PENNSYLVANIA STATE SYSTEM OF HIGHER EDUCATION

WEST CHESTER UNIVERSITY

DEPARTMENT OF GEOLOGY AND ASTRONOMY

West Chester, Pennsylvania 19383
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GUIDE TO FIELD TRIPS

C. Gil Wiswall and Charles H. Fletcher III
Editors

for the

NATIONAL ASSOCIATION OF GEOLOGY TEACHERS

Eastern Section Annual Meeting
West Chester, PA
May 20-22, 1988

Lawrence R. Matson	President
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NATIONAL ASSOCIATION OF GEOLOGY TEACHERS

1988 EASTERN SECTION ANNUAL MEETING

WEST CHESTER UNIVERSITY

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CONTENTS

NATIONAL ASSOCIATION OF GEOLOGY TEACHERS
EASTERN SECTION ANNUAL MEETING, MAY 20-22, 1988

WEST CHESTER UNIVERSITY
DEPARTMENT OF GEOLOGY AND ASTRONOMY
WEST CHESTER, PENNSYLVANIA 19383

MEETING AGENDA

FRIDAY, MAY 20

REGISTRATION: 8:00 am - 12:00 noon, 1:00 - 5:00 pm and 7:00 - 9:00 pm
Outside Room 100 of Schmucker Science Center

The following concurrent papers, workshops, and demonstrations will be in Schmucker Science Center.

9:00-9:45 am Room 50	"Unified Approach to Teaching Earth Science in Secondary Schools," Lou Casciato, West Chester University
9:00-9:45 am Room 53	"Pennsylvania; How it Got That Way," Al Palmer, Penncrest High School
9:45-10:30 am Room 50	"Digging For Dinosaurs," Sid Hotstetter, Tredyffrin Junior High School
9:45-10:30 am Room 53	"Is Sea Level Rising?," Dr. Charles Fletcher, West Chester University
10:30-11:15 am Room 50	"Raiders of the Lost Sharks - Collecting Shark Teeth in New Jersey," Ed Lauginiger, Academy Park High School
10:30-11:15 am Room 53	"Contouring by Use of Computers," Dr. Allen Johnson, West Chester University
11:15-12:00 noon Room 50	"On a Quest for the Elusive Terminal Moraine (or Pennsylvania and the Ice Age)," Rich Wagner, Wissahickon High School
11:15-12:00 noon Room 53	"Lab Structure for an Introductory Geology Course," Dr. Gil Wiswall and Dr. Charles Fletcher, West Chester Univ.
1:30-2:15 pm Room 50	"N.S.F. Model Program For Training Middle School Science and Math Teachers at S.U.N.Y. Potsdam - The Geology Component," Dr. William Kirchgasser, S.U.N.Y., Potsdam
1:30-2:15 pm Room 53	"Glaciers of Norway," Eric Mollenhauer, Deptford High School and George Bartunek, West Riverhead High School
2:15-3:15 pm Room 50	"Workshop for Teaching Using IPS Black Box," Dr. Loretta Molitor, Towson State College
2:15-2:45 pm Room 53	"North American Geologic Alliance," Dr. Frederic Goldstein, Trenton State College

NAGT EASTERN SECTION MEETING
AGENDA (cont.)
FRIDAY, MAY 20

3:15-3:30 pm Room 50	"National Earth Science Teachers Association," Pete Basile, Lower Merion High School
2:45-3:30 pm Room 53	"Geology of York County(PA), Present Investigations and Interpretations," Jeri Jones, York College of Pennsylvania
3:30-4:15 pm Room 50	"What Should Be Taught in High School and Middle School Earth Science," Dr. Michael Passow, White Plains Public Schools
3:30-4:15 pm Room 53	"Structure and Composition of Deep Sea Microbenthos Using the Scanning Electron Microscope," Dr. Brent Dugolinsky, Suny, Oneonta
4:15-5:00 pm Room 53	"Using Fossils as Time Indicators," Dr. August Simonsen, Penn State at McKeesport
4:15-5:00 pm Room 50	"Using Closed Circuit Video Microscopy in the Earth Science Classroom," Ellis Underkoffler, Brandywine School District

OTHER ACTIVITIES FOR FRIDAY, MAY 20

10:30-11:30 am & 2:30-3:30 pm	Planetarium Shows, Dr. John Stolar, West Chester Univ. (in Planetarium)
11:00 am-2:00 pm	Solar Observing, Hugh Harber, West Chester University (in Observatory)
4:00-5:00 pm Room 50	Electron Microscope and Electron Microprobe Demonstration, Dr. Art Smith, West Chester University
1:00-5:00 pm	**Field Trip** - To examine the type locality of the Wissahickon Formation in Fairmount Park in Philadelphia. Field trip leader: Al Palmer, Penncrest High School. Must have paid $5.00 for transportation - bus leaves from Church St. in front of Schmucker Science Center

FRIDAY EVENING

7:00-9:00 pm	Registration - outside of Room 100 Schmucker Science Center
8:00-9:00 pm	Planetarium Show, Dr. John Stolar, West Chester University - in Planetarium
9:00-10:30 pm	Night Observing, Hugh Harber, West Chester University (Weather permitting) - in Observatory

NAGT EASTERN SECTION MEETING
AGENDA (cont.)
FRIDAY EVENING

9:00-10:30 pm Rooms 50 & 53	Mineral Auction and Swap - Please bring specimens.

SATURDAY, MAY 21

7:00-8:00 am	Registration - outside Room 100 Schmucker Science Center
8:00 am-5:15 pm	Choose from one of the following Field Trips: (Transportation leaves from Church Street entrance of Schmucker Science Center).

Field Trip A

Geology of a Portion of the Southeastern Pennsylvania Piedmont in Chester County. Co-leaders: Dr. William A. Crawford, Bryn Mawr College and Dr. C. Gil Wiswall, West Chester University. Participants will compare rocks of the Honeybrook Upland with those of the Glenarm terrane in Chester County. The trip will begin with a traverse through the major lithologic units south of the Chester Valley. During the afternoon, the group will visit representative exposures in the Upland.

Field Trip B

This trip will depart at 7:30am

Sea-Level Rise, Coastal Erosion, and Geology of the Delaware and N. Maryland Atlantic Coasts. Leader: Dr. Charles H. Fletcher III and David A. Sinson, West Chester University. The trip will visit sites of coastal erosion and beach loss resulting in houses in the high tide surf zone, bridge endangerment, jetty collapse, and other examples of coastal engineering problems resulting from sea-level rise and human occupation of the coastline. The group will also investigate the natural geologic setting and the classic stratigraphy predicted by Walther's Law.

Field Trip C

Physiographic Trip to the Great Valley of Pennsylvania. Co-leaders: Dr. Sandra F. Pritchard, West Chester University and Dr. Percy Dougherty, Kutztown University. The trip will focus on the Great Valley between Reading, located on the crystalline rocks of South Mountain and Hawk Mountain, found on Blue Mountain, the First Ridge of the Applachians. The iron ore and radon gas of South Mountain will be discussed. A comparison of limestone and shale soils will be made. Discussions will focus on the geology of the area and the periglacial processes involved in the creation of the River of Rocks.

Field Trip D

Mineral Collecting in Chester County, Pennsylvania. Leader: David Saja, West Chester University. This trip will introduce the collector to the diversity of minerals found in Chester County, Pennsylvania. Specimens and localities will include galena, quartz, and pyromorphite from a lead-zinc mine; calcite, magnetite, chalcopyrite and pyrite from an iron mine; pyrrhotite, beryl and muscovite from pegmatite intrusions; and graphite from the mining of graphitic schist.

NAGT EASTERN SECTION MEETING
AGENDA (cont.)
SATURDAY, MAY 21

Field Trip E

Fossil Collecting at the Chesapeake - Delaware (C & D) Canal. Co-leaders: Dr. John Ehleiter, West Chester University and Edward Lauginiger, Academy Park High School. The C & D Canal in northern Delaware is well known for its wide variety of Cretaceous fossils, especially Belemnites and Exogyra. The spoil banks created during dredging of the canal yield micro- to megafossils from the Mountlaurel, Marshalltown, Englishtown, and Merchantville formations. Mr. Edward Lauginger who has studied the canal extensively and published several articles on its fossils will lead collectors to the best sites in the area.

SATURDAY EVENING
Philips Ballroom of West Chester University

7:00-8:30 pm — Annual Banquet and Awards, Buffet Meal.

8:30-9:30 pm — "Do We Teach Geology?" Guest Speaker: Dr. Robert R. Jordan, State Geologist of Delaware, and Professor at the University of Delaware

9:30-10:30 pm — Slide Swap - Bring your favorite 35mm to show and share.

SUNDAY, MAY 22

9:00-11:00 am — Annual Business Meeting

11:00 a.m. — A visit to Longwood Gardens is planned for those interested. Participants must provide their own transportation and may stay as long as they desire. Longwood Gardens charges $6 per person. However, for a group of 30 or more, the cost will be $4 per person. Longwood Gardens is about a 20 minute drive from West Chester. A description of Longwood Gardens follows. Please indicate on the Registration Form if you are interested in this activity.

Longwood Gardens

Longwood Gardens, is sure to delight anyone who loves exquisite flowers, majestic trees, and opulents architecture. Of interest are acres of formal gardens, sparkling fountains, exotic plants from all over the world, a conservatory housing 20 indoor gardens, roses and orchids in fragrant bloom year-round, an Idea Garden for home gardeners, one of the world's mightiest pipe organs, and the Terrace Restaurant and Self-Serve Cafe.

GEOLOGY OF A PORTION OF THE SOUTHEASTERN PENNSYLVANIA PIEDMONT IN CHESTER COUNTY

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West Chester University
West Chester, PA 19383

The Pennsylvania portion of the Piedmont Physiographic Province is characterized by exposures of Precambrian crystalline rocks unconformably overlain by clastic and carbonate cover sequences. In southeastern Pennsylvania, three subprovinces may be identified on the basis of distinctive geologic characteristics. To the north, the Honey Brook Upland-Mine Ridge subprovince is composed of pre-Grenville crystalline rocks mantled by Cambrian to Ordovician clastic and carbonate metasedimentary rocks. The Wissahickon schist/Baltimore gneiss terrane to the south is also composed of a Precambrian basement complex overlain by a metasedimentary cover sequence. However, the two terranes can not be directly correlated. A Cambrian to Ordovician clastic and carbonate shelf sequence which is in part correlative with the metasedimentary rocks found in the Honey Brook Upland-Mine Ridge subprovince outcrops in the Chester Valley between the two basement-cored terranes. Insufficient data exists to allow comparison of the tectonic histories of the subprovinces in this area.

This field trip will focus on the Honey Brook Upland and the Wissahickon schist/Baltimore gneiss subprovinces in Chester County. Our intent is to provide participants with a basis for comparison of the two areas. We will examine exposures of the major lithologies which comprise each terrane. Various aspects of the metamorphic and deformational histories of these rocks will be emphasized.

INTRODUCTION

The Piedmont Province extends in a continuous belt from Alabama to Newfoundland. This Province may be characterized as a belt of structurally-bounded, deformed and metamorphosed, eugeoclinal sediments and volcanics of late Precambrian to early Paleozoic age (Williams and Hatcher, 1983). These rocks are associated with scattered exposures of 1.0 Ga Grenville basement which vary widely in size. Mafic to ultramafic bodies, many of unknown origin, occur along the contact of the Piedmont with the Cambro-Ordovician North American shelf sequence to the west.

In the southern Appalachians, the structural position east of the miogeoclinal sequence of the Piedmont and its fault boundaries makes it a prime candidate for interpretation as an accreted terrane. It seems clear that at least the westernmost exposures of the Grenville and associated cover are allochthonous and have been transported significant distances to the northwest during the Alleghanian orogeny (e.g. Cook and others, 1979).

A recent tectonic synthesis of the Taconic orogeny (Stanley and Ratcliffe, 1985) interprets the Piedmont-like rocks in New England as the eastern rifted margin of cratonic North America overlain by continental slope and rise sedimentary rocks. This package was deformed during the Taconic event in response to the accretion of an island arc complex to the eastern margin of the craton. Although the exposures of Grenville rocks are thrust bounded, the magnitude of transport is minimal compared with that in the southern Appalachians. Thus, comparison of the northern and southern Piedmont terranes suggests possibly similar early histories but significantly different responses to the Paleozoic orogenies.

Models developed for the relatively well studied northern and southern Appalachians converge on a poorly understood portion of the province in southeastern Pennsylvania, Delaware, and northeast Maryland. Here, the wide expanse of the southern terrane narrows and changes strike as it heads into New England. In the southern Piedmont, the major deformation is Alleghanian in age whereas, Taconic structures predominate in New England. Several exotic terranes have been identified both to the north and south. The area in which the differences between the northern and southern Appalachians must be reconciled is centered on the Pennsylvania Piedmont.

This trip is intended to illustrate some current ideas concerning the geologic and tectonic evolution of this critical area. Recent accounts of the geology of the Honey Brook Upland are given in Crawford and Hoersch, 1984 and Crawford et al, 1971; an overview of the metamorphic history of southeastern Pennsylvania is found in Crawford and Crawford, 1980. [Reprints of these paper are available, upon request, from W. A. Crawford.] Ideas about the area south of the Chester Valley are based on work in progress (by CGW) and therefore, are preliminary in nature and based on unpublished data.

REGIONAL RELATIONSHIPS

Introduction

In general, the Piedmont Province in Pennsylvania consists of 1.0-1.1 Ga crystalline rocks which are unconformably overlain by cover sequences of various origins. As elsewhere, the lithologies present are consistent with

a cratonal margin suite including clastics, carbonates, volcaniclastics, and mafic volcanics. The Province is covered on the east by the Coastal Plain, and is bounded on the north and west by the Juro-Triassic Newark and Gettysburg basins. The region may be divided into three subprovinces (Figure 1): the Honey Brook Upland-Mine Ridge, the Chester Valley, and the Wissahickon schist/Baltimore gneiss terrane.

These rocks have been the source of controversy for nearly 100 years. Initial studies by Florence Bascom, her colleagues, and students produced geologic maps of such quality that relatively little revision has been required (Bascom, Darton, et al, 1909; Bascom, Clark, et al, 1909; Bascom and Miller, 1920; Smith, 1922; Knopf and Jonas, 1929; Bascom and Stose, 1932, 1938). It is interesting to note that the early workers in the Piedmont identified several major problems which continue to occupy geologists today. Chief among these are the macroscopic structure responsible for exposures of the basement complex, the age and stratigraphic makeup of the metasedimentary rocks overlying the Baltimore gneiss, and the structural relationship between the three subprovinces.

The solutions to these problems play an integral role in any attempt to construct a tectonic history for the Pennsylvania Piedmont Province as a whole. Comparison of the Honey Brook Upland-Mine Ridge subprovince with the Wissahickon schist/Baltimore gneiss terrane yields enigmatic results. In both areas, the basement complexes are unconformably overlain by sedimentary sequences of similar affinities. However, there is no deep water facies similar to that represented by the Wissahickon schist associated with the Cambro-Ordovician sediments overlying the Honey Brook Upland-Mine Ridge block. Rather, a carbonate sequence is present. Compositionally, the Baltimore gneiss is dissimilar to the gneisses north of the Chester Valley. Both areas have experienced at least two metamorphisms; a granulite facies event during the Grenville orogeny followed by greenschist through amphibolite facies metamorphism during the Taconic event. Both blocks are probably allocthonous but insufficient structural data is available to provide a consistent deformational history within a given block, much less compare sequences between blocks. Therefore, much additional work is necessary before a regional tectonic synthesis emerges.

Wissahickon Schist/Baltimore Gneiss Terrane (WS/BGT)

The WS/BGT constitutes the largest subdivision of the Pennsylvania Piedmont province. As such, a complete review of this area is beyond the scope of this report. The discussion which follows addresses only that portion of the WS/BGT covered by the field trip route.

Geologic mapping confirms the presence of four major lithologic units in the area south of the Chester Valley. The oldest rocks are Grenville age pyroxene granulite and quartzofeldspathic granulite gneisses (Baltimore gneiss of Bascom, Clark, et al, 1909). Within the area covered by the field trip route, these rocks occur in two massifs. The Poor House Prong is on the north; the West Chester Prong on the south (Figure 2). These gneisses are unconformably overlain by schists and phyllites of the Wissahickon, Peters Creek, and Octoraro formations which are all composed primarily of interbedded pelitic and psammitic metasediments.

Two metamorphic events have affected the area (Crawford and Crawford, 1980). A granulite grade event (M1) affecting the Baltimore gneiss has

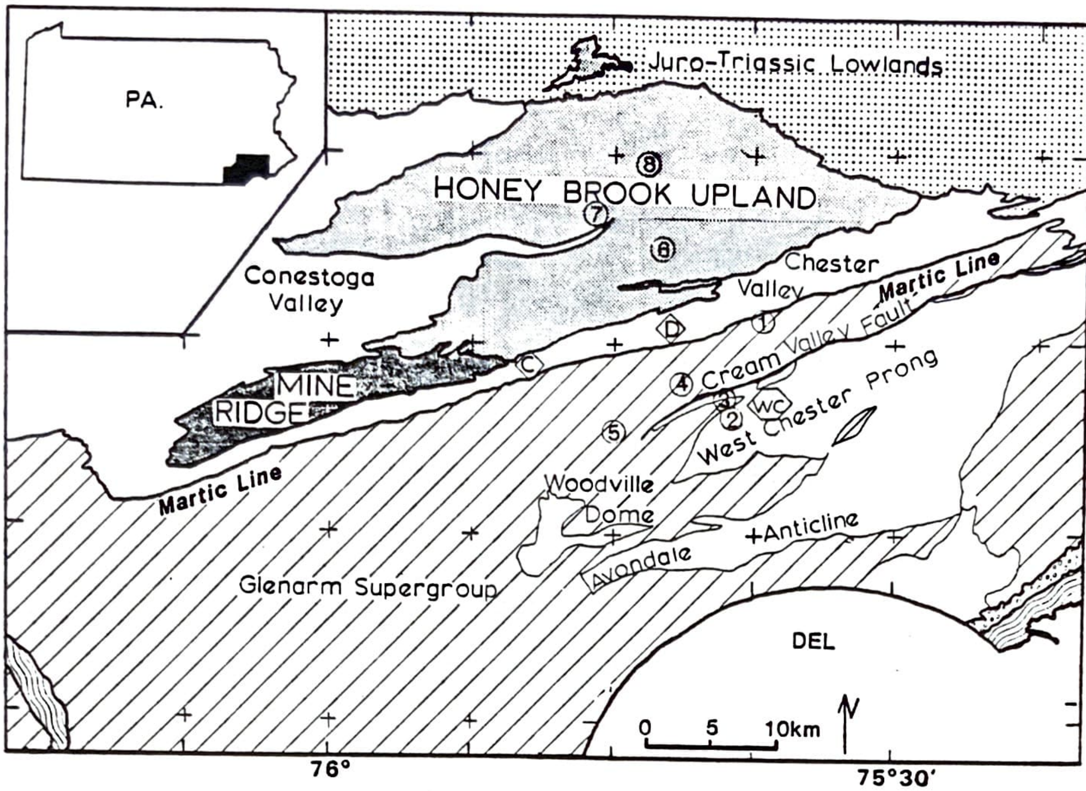


Figure 1. Physiographic subdivisions of the southeastern Pennsylvania Piedmont. Numbers 1 through 8 mark the approximate location of each stop. C = Coatesville, D = Downingtown, and WC = West Chester. (After Hoersch and Crawford, 1988).

been dated at approximately 1.0 Ga or Grenville in age (Grauert et al, 1973). No evidence of M1 has been recognized in the cover sequence indicating that this event predates deposition of the WS/BGT sediments. A lower Paleozoic dynamothermal event (M2) corresponding to the Taconic orogeny affected all rocks in the area (Grauert et al, 1973). This event resulted in retrograde reactions in some of the Baltimore gneiss yielding upper amphibolite facies assemblages (e.g. Wagner and Srogi, 1987). M2 isograds in the WS/BGT metasedimentary rocks show a general increase in grade from lower greenschist facies in the northwest to upper amphibolite facies in the southeast. There is some evidence of post-M2 retrograde metamorphism affecting the rocks in the vicinity of the Cream Valley fault (M. L. Crawford, personal communication, 1988), but additional work needs to be completed in order to document the existence and determine the nature and extent of this event.

Mesoscopic folds present in the area can be divided into two groups based on style of deformation. The two groups are separated by the Cream

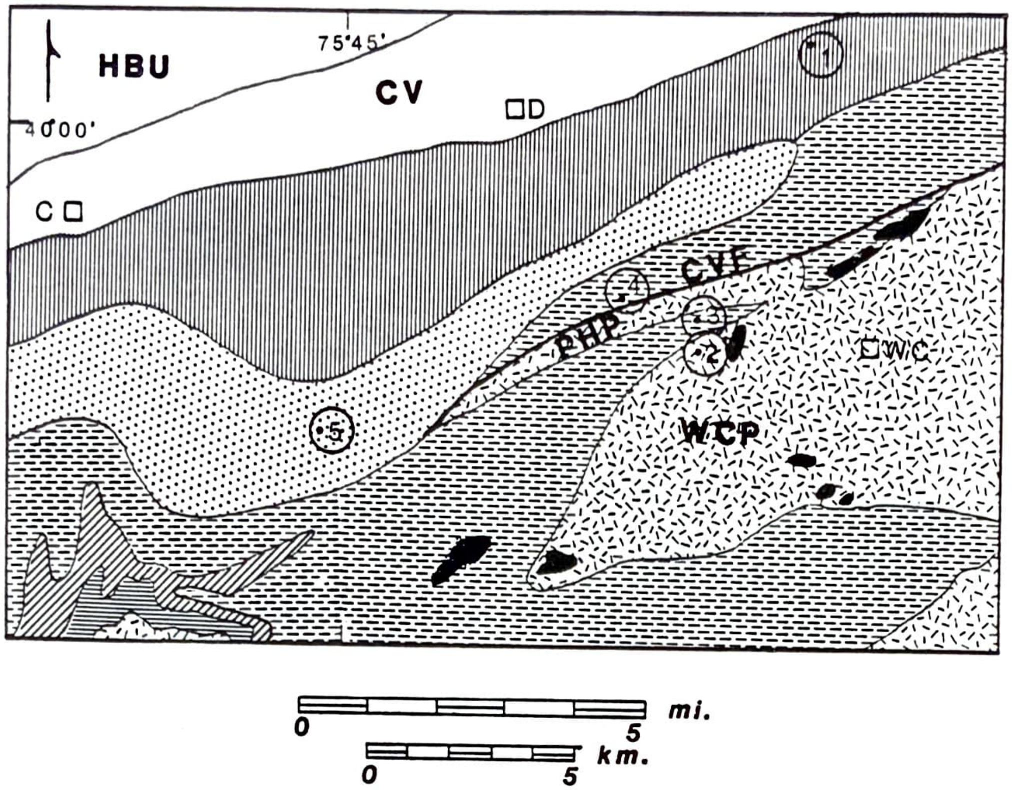


Figure 2. Geologic map of the Wissahickon schist/Baltimore gneiss terrane (after Berg et al, 1980). Numbers 1 through 5 mark stop locations. C = Coatesville, D = Downingtown, WC = West Chester; HBU = Honey Brook Upland, CV = Chester Valley, CVF = Cream Valley fault, PHP = Poor House Prong, WCP = West Chester Prong. Vertical lines: Octoraro phyllite. Dots: Peters Creek schist. Dashes: Wissahickon schist. Diagonal lines: Cockeysville marble. Horizontal lines: Setters quartzite. Random dashes: Baltimore gneiss. Black: serpentinite.

Valley fault (Figure 2). The group south of the fault may be characterized as tight, asymmetric, drag-type folds which formed under clearly ductile conditions; probably syn- through post-high grade metamorphism. The northern group of folds are crenulations which formed under conditions of lower temperature and pressure. It seems clear that the two fold groups did not form at the same time in rocks with the present geographic distribution.

South of the Cream Valley fault, the earliest fabric element present in either the gneiss or the schist is a metamorphic foliation. In the Baltimore gneiss, granulite facies metamorphism produced gneissic layering (S1). S1 is variably developed throughout the area, yielding rocks which

are weakly to strongly foliated as a result of M1. The Wissahickon formation exhibits a pervasive metamorphic schistosity (S2) which is subparallel to compositional layering (SØ). Rare isoclinal folds (F2) in SØ which are axial planar to S2 show that folding and transposition (D2) accompanied the metamorphism responsible for S2 formation.

The earliest foliation in both rock types (S1 in the gneisses and S2 in the Wissahickon) experienced subsequent deformation (D3). Although F3 mesoscopic structures found in the Peters Creek and Wissahickon schists may be divided into three generations on the basis of cross-cutting relationships, similarity in style and axial orientation suggest that these structures represent a continuous progressive deformation. In the schists, the oldest structures (F3a) are outcrop scale, tight to isoclinal, inclined to recumbent folds which deform S2. Axial surfaces dip to the southeast with near horizontal axes. Asymmetry of these drag-type folds shows consistent southeast over northwest transport. F3c folds are centimeter scale, close to tight, sharp crested, inclined buckle folds developed on the limbs of F3a folds. They show similar axis and axial plane orientations to F3a folds and exhibit the same sense of movement. The short limbs of these folds are cut by shear bands so that adjacent antiformal and synformal hinges are transposed. F3b folds show intermediate characteristics between these endmembers. In the gneisses, different generations of F3 folds have not been recognized. Correlation is based on similarity in style and orientation with the F3 folds developed in the schists. During D3, the gneisses apparently behaved more competently than the schists. F3 in the gneisses are outlined by centimeter scale shear zones. These shear zones cut the pre-existing gneissic layering (S1), commonly at high angles. The geometry and movement picture derived from these folded shear bands are similar to those described for F3 in the schists.

The relationships discussed above suggest that D3 was a compressional tectonic event consistent with nappe formation and emplacement. The relationship between D2 and the coincident Paleozoic metamorphic event (M2) with D3 is not clear at this time. In thin section, D3 structures are defined by bent, unrecrystallized phyllosilicates (S2) indicating that D3 occurred after the peak of metamorphism. However, whether D3 is syntectonic with M2 or a later, unrelated tectonic event can not be resolved at present.

The following scenario is a working hypothesis presented for discussion. M2 has been dated as Taconic in age. The Taconic orogeny is envisioned to represent the collision of North America with an island arc complex (e.g. Wagner and Srogi, 1987). Since D3 fold geometry and movement picture are consistent with such a tectonic environment, D2/M2 and D3 probably represent the same tectonic event and are continuous in time. Metamorphism (M2) and isoclinal folding (D2) began as North America entered the thermal and stress regimes of the subduction zone associated with an island arc. As docking of the island arc began, nappes were formed at depth in response to the collision. Thrusting of the island arc complex onto North America forced nappe displacement toward the continent and to shallower levels in the crust, thereby passing through the brittle/ductile transition. This initiated the development of shear bands which replaced folding as the dominant mechanism of strain in the metasediments. The gneisses, being more competent, initially deformed by ductile shear along thin deformation zones producing planes of anisotropy, commonly at high

angles to S1. As nappe emplacement proceeded, these deformation zones became mechanically significant and folding occurred. In this model, the Cream Valley fault would represent the surface along which nappe emplacement occurred. This may explain the difference in metamorphic grade and structural style on either side of the fault. If this is the case, the Cream Valley fault represents a more significant tectonic boundary than has been previously recognized. This hypothesis fits the existing data nicely, but requires further scrutiny.

North of the Cream Valley fault, structural relationships are still unclear. The Peters Creek schist and Octoraro phyllite show a pervasive and consistent schistosity defined by a low grade mineral assemblage. Several fabric elements overprint this schistosity. These include:

1. Multiple sets of secondary cleavage resulting in an undulatory schistosity. Such fabrics, described as extensional crenulation cleavage (Platt and Vissers, 1980) or normal slip crenulations (Dennis and Secor, 1987) are attributed to ductile shearing of strongly anisotropic rock. In this area, these crenulations are not penetrative at the macroscopic scale. They appear to occur in discrete zones, possibly associated with the Cream Valley fault. Kinematic indicators are consistent with a southeast over northwest sense of transport.

2. Conjugate, asymmetric kink folds. These folds exhibit shallowly-plunging axes and moderate to steeply-dipping axial surfaces. Minor dip slip displacement along axial surfaces locally produces a spaced cleavage at high angles to the predominant schistosity and intersection lineations on foliation surfaces. In addition, crenulation lineations are common.

3. Spaced crenulation cleavage of zonal type (Gray, 1977) associated with microfolds in the predominant foliation. Cleavage surfaces are of millimeter spacing and produce intersection lineations on foliation surfaces. These structures are common throughout the Octoraro phyllite but seem to develop only in certain layers.

Age relationships amongst these structural elements are unclear. It is presently uncertain if the folds north and south of the Cream Valley fault formed at the same time during the same deformational event. Further, it is not clear whether the present mineralogy represents peak metamorphism or is a retrograde assemblage. The possibilities include: 1) that these rocks were raised to amphibolite facies during M2 and subsequently experienced thorough retrogression, 2) that the rocks were metamorphosed during M2 but never exceeded greenschist conditions, or 3) that they experienced a different metamorphic history all together. Of these, the latter two are most consistent with the tectonic history proposed above. The mesoscopic structures occurring in the rocks north of the fault formed by kinking, presumably at low temperatures and pressures. South of the fault, the earlier mesoscopic structures formed by ductile flow. This suggests that the rocks north of the fault have not been raised to upper amphibolite

grade. However, a subsequent deformational event of sufficient intensity to obliterate all earlier fabrics is possible. Song and Hill (1988) proposed the existence of a major dextral shear zone coinciding with the outcrop width of the Octoraro phyllite through the northern most portion of this area. Such a shear zone could account for the relationships observed. Clearly, additional work is required in order to distinguish between these possibilities.

Honey Brook Upland (HBU)

The HBU (Figure 1) contains pre-Grenville age crystalline rocks overlain by a sequence of clastic and carbonate Cambrian to Ordovician metasedimentary rocks (Figure 3). Mineral assemblages found in the crystalline rocks and ^{40}Ar-^{39}Ar cooling ages obtained from hornblendes and biotites in them demonstrate they have undergone two episodes of metamorphism. These granulite and amphibolite grade gneisses obtained their high grade assemblages during the Grenville event and underwent a retrograde metamorphism to greenschist grade in the Taconic event. The overlying sediments were raised to the greenschist facies during the later event.

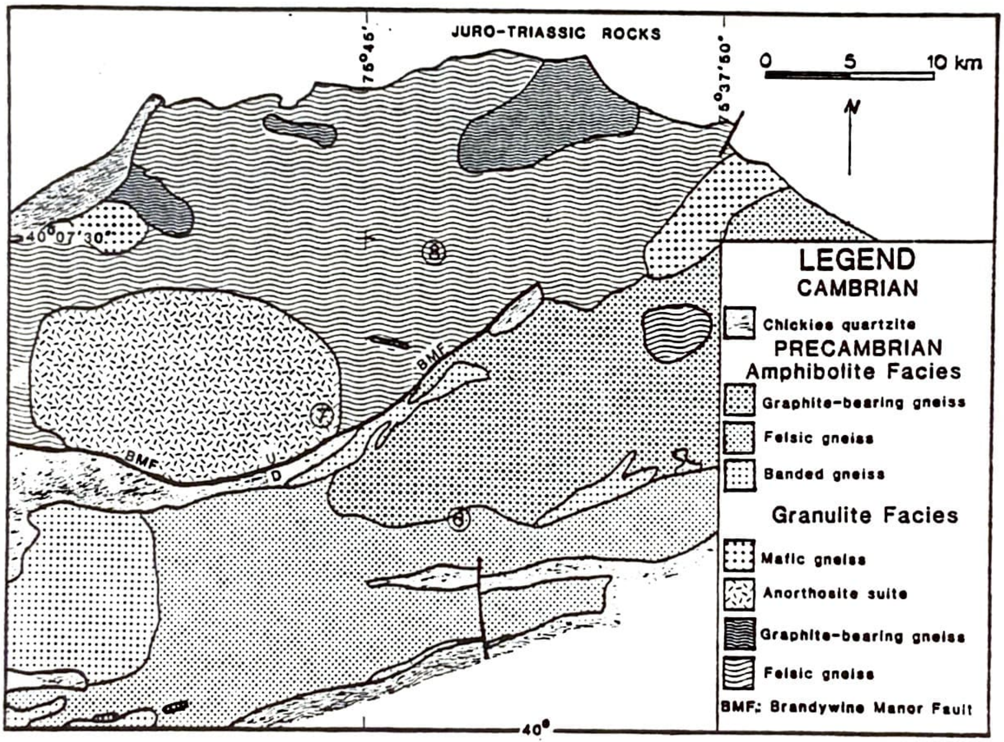


Figure 3. Geologic map of the Honey Brook Upland. (From Crawford and Hoersch, 1984).

Granulite Grade Rocks Charnockites, mafic granulites (metabasalts), and an anorthosite suite comprise the granulite grade rocks that lie to the north of the Brandywine Manor fault (Figure 3). Microcline perthite, hypersthene, light green augite, and dark green to brown hornblende are the indicator minerals for low pressure granulite grade facies in the charnockites and metabasalts. Some charnockites are graphite bearing. Rock types in the anorthosite suite include anorthosite, leuco-hornblende gabbro and hornblende gabbro.

Amphibolite Grade Rocks Felsic to intermediate amphibolite grade gneisses and banded amphibolites comprise this suite (Figure 3). Whole rock major element trends demonstrate that the protoliths were volcanic rocks of the basalt-andesite-dacite-rhyolite family. Plagioclase (An_{40-65}) dark green hornblende, and pink garnet all indicate upper amphibolite facies metamorphism. Some felsic gneisses are graphite-bearing.

Greenschist Grade Rocks An overprinting mineral assemblage of blue green amphibole rims around hornblende, decomposition of pyroxenes, and saussuritization of plagioclase demonstrates a retrogression to greenschist conditions in the crystalline rocks. Only the pelitic members of the overlying metaclastic and metacarbonate rocks have the proper chemical composition for the development of the greenschist facies indicator minerals chlorite, biotite, muscovite, quartz, and epidote.

Structures The poles to foliation of the crystalline rocks exhibit considerably more scatter than do the poles to bedding in the Chickies quartzite. The foliation in the crystalline rocks dips steeply to the south and has an average trend of ENE (Figure 4). The poles to bedding planes in the Chickies quartzite (Figure 5) suggest a girdle distribution which is indicative of participation in but a single folding event. The scatter of poles to foliation in the crystalline rocks suggests a more complex structural history. This structural data, the metamorphic history (Crawford and Crawford, 1980 and Crawford and Hoersch, 1984), and $^{40}Ar/^{39}Ar$ cooling ages (Sutter et al, 1980) suggest the crystalline rocks were folded during the Grenville event and later, along with the mantling metasedimentary rocks, in the Taconic event.

Geologic History See Crawford and Hoersch, 1984, for detailed information that supports the following geologic history.

1. The covering of basement charnockites by extrusion of a calc-alkaline volcanic suite accompanied by coeval deposition of volcaniclastic sediments.

2. Burial of the entire sequence, deformation, and high grade metamorphism during the Grenville orogeny.

3. The timing of the stock-like intrusion of the anorthosite massif into the charnockites is uncertain. It could be pre-, syn-, or post-extrusion of the volcanic suite or perhaps it was part of the Grenville event.

4. The source of the graphite found in some charnockites and felsic amphibolite grade gneisses may have been CO streaming off the anorthosite intrusion into the charnockites. The current location of the graphite at the granulite-amphibolite boundary may have been set during the Grenville event.

4. Mid-late Precambrian uplift and erosion of the crystalline rocks, and deposition of the Cambro-Ordovician clastic-carbonate sequence.

5. Burial and retrograde metamorphism during the Taconic orogeny.

6. Post Taconic uplift accompanied by movement on the Brandywine Manor fault.

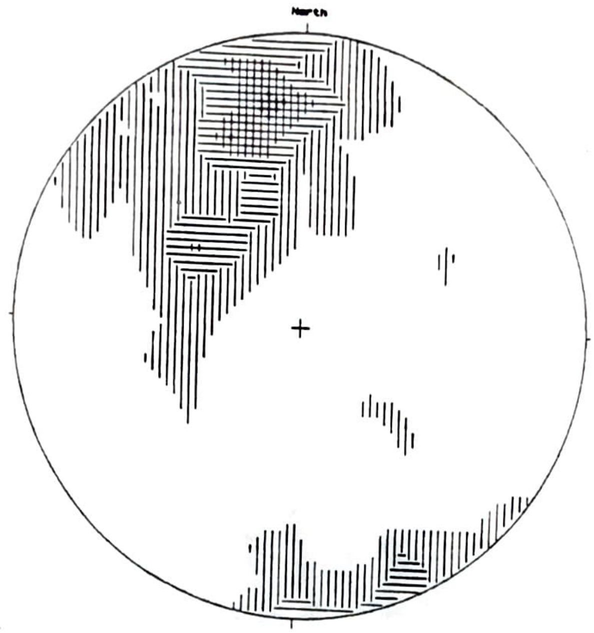


Figure 4. Stereographic projection of poles to foliation for Precambrian crystalline rocks of the Honey Brook Upland. 227 points compiled from: Demmon, 1977; Huntsman, 1975; Postel, 1951; Trautwein, 1983; and Thomann, 1977. Contour interval = 2 % per 1 % area; maximum concentration = 8 %. Plot produced using SPLOT by Darton Software.

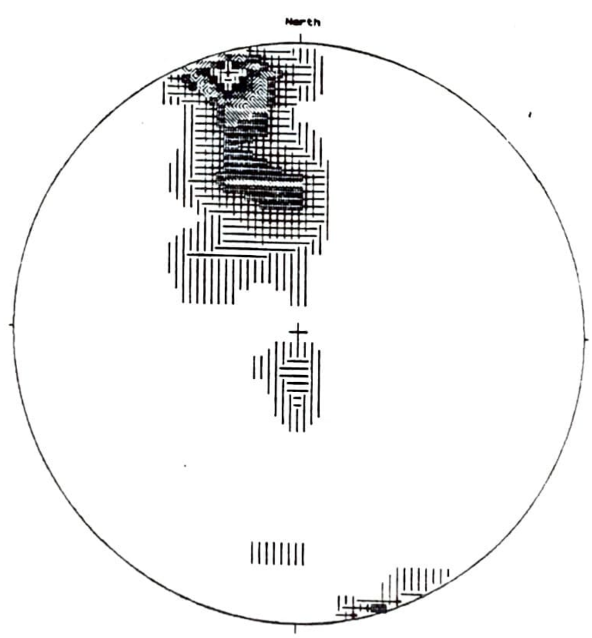


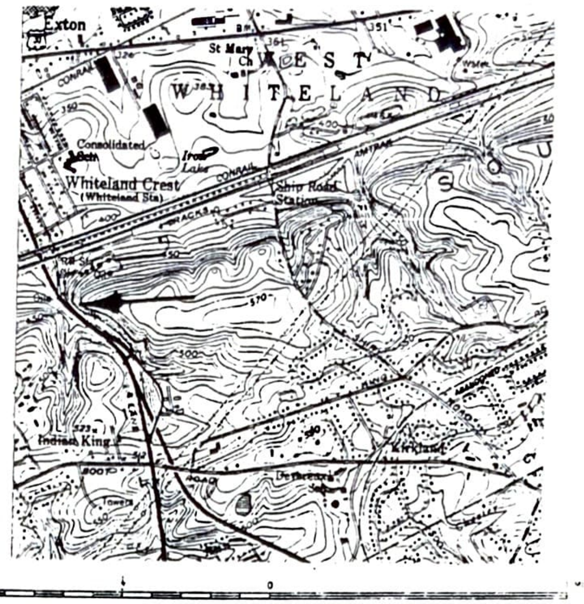
Figure 5. Stereographic projection of poles to bedding planes in Cambrian Chickies quartzite formation. 63 measurements compiled from: Demmon, 1977; Huntsman, 1975; Postel, 1951; Trautwein, 1983; and Thomann, 1977. Contour interval = 2 % per 1 % area; maximum concentration = 26 %. Plot produced using SPLOT by Darton Software.

MILEAGE		TRAVEL TIME			
TOTAL	INCREM	TOTAL	INCREM	DIRECTION	DESCRIPTION
0.00	0.00	0000	0000		Leave WCU motor pool lot
0.10	0.10			RIGHT	New Street
0.30	0.20			RIGHT	Price Street
0.60	0.30			LEFT	High Street/PA 100 N
5.00	4.40			STRAIGHT	Continue on PA 100 N: follow overpass and entrance ramp to PA 100/US 202 N
5.50	0.50	0012	0012	PARK	Pullout on right shoulder
		0047	0035		**STOP 1: Octoraro phyllite**
				STRAIGHT	Proceed north on PA 100 N
5.80	0.30			RIGHT	Howard Street
5.85	0.05			LEFT	Crest Street
6.00	0.15			LEFT	Bartlett Street
6.05	0.05			LEFT	PA 100/US 202 S
6.90	0.85			RIGHT	PA 100 S to West Chester
9.70	2.80			RIGHT	Taylors Mill Road
10.00	0.30			LEFT	New Street
10.02	0.02			LEFT	Mill Street
10.10	0.08			RIGHT	US 322 W Bypass
11.00	0.90			CROSS	US 322 to Highland Road
11.50	0.50			RIGHT	PA 162 W
13.00	1.50			LEFT	Deborah's Rock Farm road
13.35	0.35	0102	0015	PARK	Lot on left by red barn
		0202	0060		**STOP 2: Precambrian gneisses of West Chester Prong**
					Retrace route to PA 162 E
13.70	0.35			RIGHT	PA 162 E
13.90	0.20			LEFT	Creek Road
14.20	0.30	0204	0002	PARK	Grass pullout on left. Walk south 0.15 mi to outcrop on hillside
		0239	0035		**STOP 3: Wissahickon schist**
					Continue north on Creek Road
14.50	0.30			LEFT	US 322 W
15.50	1.00			LEFT	Sugarsbridge Road
15.52	0.02			LEFT	Waltz Road
15.55	0.03	0244	0005	PARK	Pull off road to left
		0319	0035		**STOP 4: Wissahickon schist**
					Continue south on Waltz Road
16.55	1.00			RIGHT	Telegraph Road
17.50	0.95			STRAIGHT	Telegraph Rd joins Sugarsbridge Road
17.60	0.10			STRAIGHT	Telegraph Road leaves Sugarsbridge Road

18.40	0.80			CROSS	Marshallton-Thorndale Road
18.60	0.20			RIGHT	Strasburg Road
21.20	2.60			LEFT	Stargazers Road by Romansville General Store
21.80	0.60			STRAIGHT	Youngs Road (Stargazers turns sharply to left)
22.70	0.90			RIGHT	Laurel Road
22.80	0.10	0331	0012	PARK	Pull off road to right
		0406	0035		**STOP 5: Peters Creek Schist**
					Continue west on Laurel Road
24.80	2.00			CROSS	Strasburg Road in Mortonville
25.60	0.80			LEFT	Sawmill Street
27.00	1.40			STRAIGHT	Stop sign at unmarked intersection
28.80	1.80			STRAIGHT	Stop sign: becomes S. 1st Avenue
29.60	0.80	0422	0016	CROSS	US Business 30; becomes PA 82 N
29.80	0.20				Harpers phyllite in outcrop on right
30.20	0.40				Chickies quartzite on right
30.55	0.35				Honey Brook Upland amphibolite gneiss intruded by pegmatite
31.20	0.65			STRAIGHT	Pass under US 30 overpass
31.45	0.25			CROSS	PA 340; road narrows
36.00	4.55			LEFT	US 322 W
38.20	2.10	0433	0011	LEFT	Parking lot, Pedlars Inn
		0533	0060		**LUNCH**
				RIGHT	Proceed southeast on US 322 E
40.20	2.10			CROSS	PA 82
43.80	3.60			LEFT	Hopewell Road in Guthriesville
44.70	0.90			STRAIGHT	Village of Corner Ketch
46.90	2.20			LEFT	PA 282 N
46.95	0.05			RIGHT	Dorlan Mill Road
47.25	0.30	0549	0016	LEFT	Spillway access road
					Proceed approximately 0.2 mi to top of dam
		0629	0040		**STOP 6: Amphibolite gneiss**
					Return to Dorlan Mill Road
47.25				RIGHT	Dorlan Mill Road
47.55	0.30			RIGHT	PA 282 N
53.15	5.60	0640	0011	PARK	Gravel parking lot on right
		0720	0040		**STOP 7: Honey Brook Anorthosite**
				LEFT	Proceed south on PA 282 S
54.85	1.70			RIGHT	Marshall Road

55.60	0.75			STRAIGHT	Marshall Road becomes Little Conestoga Road
56.00	0.40			STRAIGHT	Steyer Road
57.40	1.40			RIGHT	Greenridge Road
58.10	0.70			LEFT	Font Road
59.30	1.20			RIGHT	Fairview Road
59.80	0.50			LEFT	PA 401 W
59.85	0.05	0735	0015	PARK	Use pullout on left
		0815	0040		**STOP 8: Granulite gneiss**
					Proceed east on PA 401 E
61.05	1.20			RIGHT	PA 100 S
72.05	11.00			RIGHT	Price Street
72.35	0.30			LEFT	New Street
72.55	0.20			LEFT	WCU motor pool driveway
72.65	0.10	0842	0027	PARK	END OF TRIP

STOP 1: OCTORARO PHYLLITE



LOCATION: Malvern 7 1/2' quadrangle. This outcrop is located on the east side of PA 100 about 15 meters south of the railway overpass. The shoulder is sufficiently wide to accommodate large busses. However, the roadway is heavily traveled so that ample care should be taken to ensure the safety of trip participants.

GENERAL STATEMENT: This exposure of the Octoraro phyllite lies near the contact with the Cambro-Ordovician Conestoga limestone. This contact, better known as the Martic line, has been the source of controversy for decades. It has been variously interpreted as a stratigraphic contact, a thrust fault, and a crustal scale dextral shear zone.

LITHOLOGY: Although originally mapped as a schist, this unit is more properly called phyllite. Major minerals include muscovite, chlorite, and albite with varying amounts of quartz. Highly deformed quartz stringers, pods, and lenses are common here. Millimeter scale pyrite crystals and pseudomorphs of limonite after pyrite occur locally.

STRUCTURE: The fabric of this outcrop is typical of that seen throughout the Octoraro phyllite. Intersecting kink fold axes, probably members of a conjugate pair, are easily observed on the foliation surface at the north end of the outcrop. This interpretation is strengthened by a box fold which occurs close to ground level at about the midpoint of the exposure. Shear displacement parallel to the dip of axial surfaces is commonly associated with these folds. Quartz veins filling apparent tension gashes developed along the axial planes of these folds are locally present. A closely spaced zonal crenulation cleavage produces intersection and crenulation lineations which are subparallel to the dip of the pervasive schistosity, and intersect the lineations resulting from kink folds at relatively high angles. The relative age of the structural elements present here is uncertain at this time.

STOP 2: GNEISSES OF THE WEST CHESTER PRONG

LOCATION: Unionville 7 1/2' quadrangle. Those wishing to visit this exposure should first obtain permission from the owner, Mr. Samuel Wagner, Deborah's Rock Farm. The outcrop is situated on the southwest bank of the East Branch of Brandywine Creek approximately .2 mi downstream from the bridge on PA 162. Vehicles may be parked next to the large red barn at the top of the farm's driveway. Walk approximately 250 feet northeasterly to the top of the outcrop. Very steep slopes and poor footing make this outcrop somewhat dangerous. The exposure is best studied by following an old fence line down the north flank of the outcrop to the river level, then walking downstream along the face.

GENERAL STATEMENT: This exposure is located on the northwestern flank of the West Chester Prong. The contact between these gneisses and kyanite-bearing Wissahickon schist (Stop 3) lies just north of Route 162. The Cream Valley fault is approximately 0.7 miles to the northwest.

LITHOLOGY: Felsic and mafic phases of the gneiss exhibit complex contact relationships at this outcrop.

STRUCTURE: These rocks display several fabric elements suggesting a complex structural history. The oldest fabric element is a gneissic layering (S1), presumably produced during the Grenville event 1.0 Ga ago. Protomylonitic to mylonitic deformation zones (S2) cut S1, often at high angles. These ductile deformation zones have been folded during D3. The folded shear zones pictured in Figure 6 occur at the northern end of the outcrop about 50 feet above the river. Folding was accompanied by stretching parallel to the fold axes. Good examples of this lineation are exposed on the underside of an overhang on the south end of the outcrop at river level. Figure 7 demonstrates that folding and stretching occurred about a shallow plunging axis which parallels the Cream Valley fault.

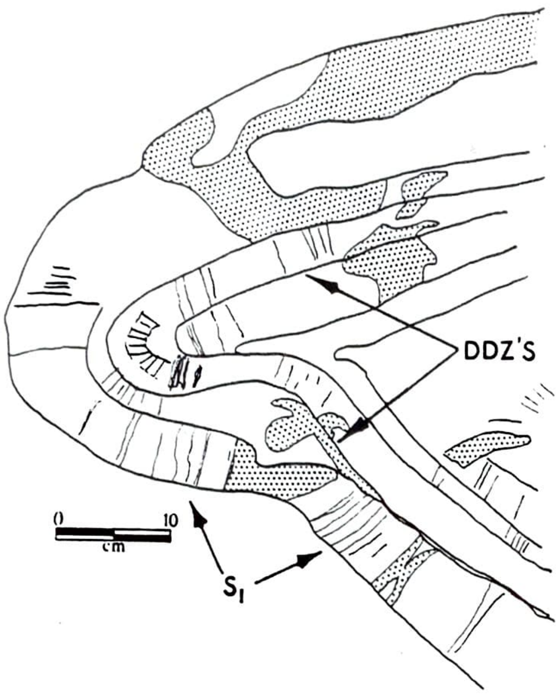


Figure 6. Sketch from a photograph of ductile deformation zones (DDZ'S) folded during D3. View is toward SE.

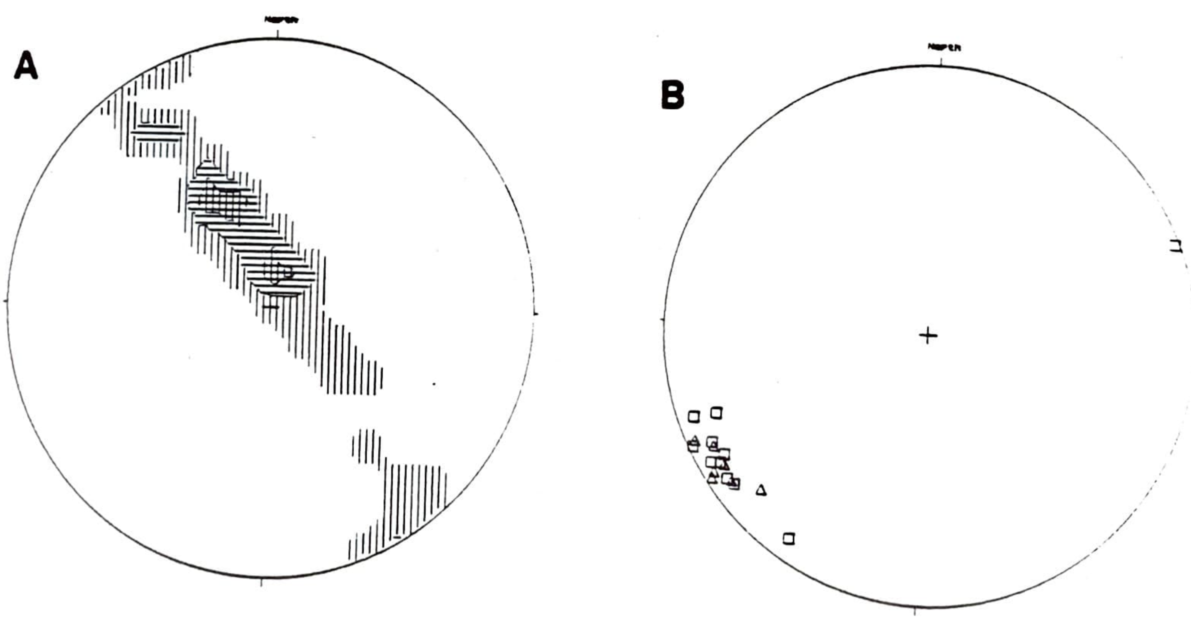


Figure 7. Stereographic projections of (A) 19 poles to ductile deformation zones and (B) 11 minor fold axes (boxes) and 7 stretching lineations (triangles) at Stop 2. Contour interval in (A) = 5% per 1% area; maximum contour = 15 %. Plots produced using SPLOT by Darton Software.

STOP 3: UPPER AMPHIBOLITE GRADE
WISSAHICKON SCHIST

LOCATION: Unionville 7 1/2' quadrangle. Several scattered exposures crop out on the steep hillside east of Creek Road. A maximum of two passenger vans may be parked in small pullouts on the west side of the roadway across from the outcrops. Larger groups may find parking in the spot identified in the road log, however, the property owners should be notified of your intentions.

GENERAL STATEMENT: At this location, upper amphibolite grade Wissahickon schist lies between the Poor House and West Chester Prongs. The relationship between the two Grenvillian massifs at depth is uncertain. The Cream Valley fault, marking the northern contact of the Poor House Prong, lies less than 0.5 mi. across strike to the northwest.

LITHOLOGY: The Wissahickon schist at this locality is pelitic as indicated by the presence of kyanite. Mineralogically, the rock consists of staurolite, garnet, kyanite, biotite, muscovite, plagioclase, and quartz. Grain size is coarser than is typical of the unit in this area. Numerous pegmatitic pods and lenses are distributed throughout the rock.

STRUCTURE: The fabric of this rock suggests strong deformation. A distinct but irregular foliation is apparent on outcrop faces oriented parallel to the hillslope. Viewed on surfaces trending into to the hillslope, a strong linear fabric can be seen. Several elements contribute to the lineation including the long axes of kyanite crystals, the line of intersection of coarse muscovite plates, and the long dimension of pegmatitic and quartz pods and lenses (Figure 8). Note that this lineation is parallel to the macroscopic F3 fold axis at Stop 2 (Figure 7).

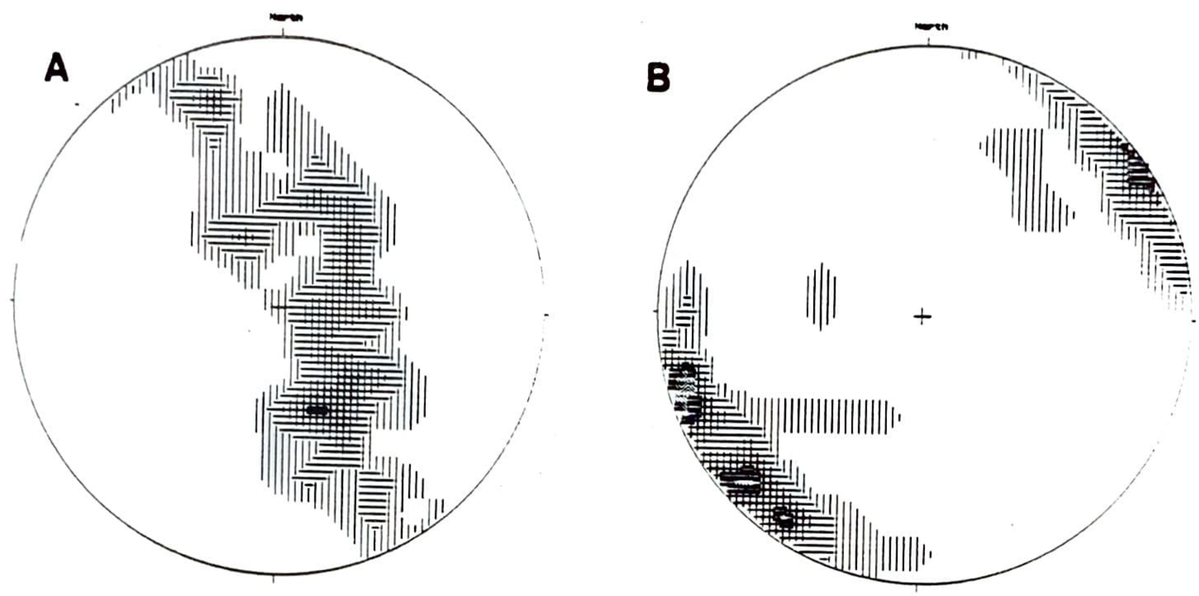


Figure 8. Stereographic projections of (A) 50 poles to 001 planes of coarse muscovite and (B) 50 c-axis orientations of kyanite at Stop 3. Contour interval = 2 % per 1 % area; maximum concentration = 10 % in (A) and 14 % in (B). Plots produced using SPLOT by Darton Software.

STOP 4: UPPER GREENSCHIST GRADE WISSAHICKON SCHIST

LOCATION: Unionville 7 1/2' quadrangle. This small exposure lies within 200 feet on U.S. 322 at the intersection of Sugarsbridge and Waltz Roads. Plough Farm and Garden Center, situated on the northeast side of U.S. 322, marks the turn onto Sugarsbridge Road. The intersection with Waltz Road is encountered immediately after leaving U.S. 322. Parking is limited to the roadway, however Waltz Road is so lightly traveled that this poses little safety hazard.

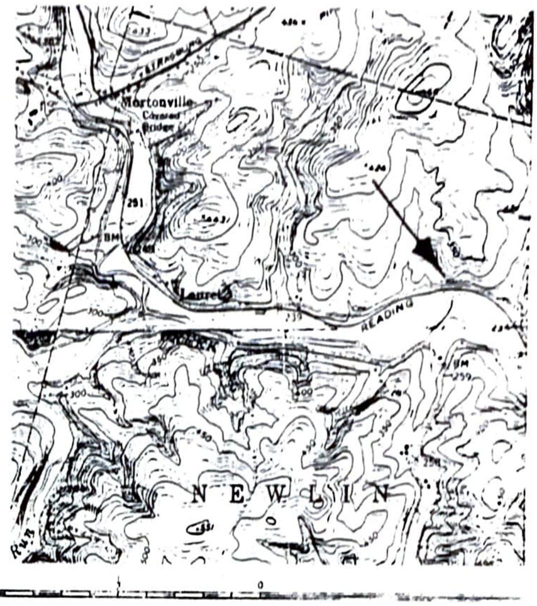
GENERAL STATEMENT: This outcrop lies approximately 0.25 mi. north of the Cream Valley fault. We have traveled about 0.75 mi. across strike from Stop 3 and crossed the Poor House Prong and Cream Valley fault. Note the distinctly different character of the Wissahickon schist here when compared with the last stop.

LITHOLOGY: Although somewhat more quartzose than the rock at Stop 3, the Wissahickon here contains a lower grade mineral assemblage and is finer grained. The present mineralogy consists of garnet, chlorite, muscovite, plagioclase, and quartz. No biotite or kyanite has been found. Accessory green tourmaline and chlorite as rims and along fractures in garnets suggest retrograde metamorphism.

STRUCTURE: The rock fabric is the most distinctive difference between the Wissahickon here and that at Stop 3. Three sets of S-surfaces are present. The oldest is defined by the preferred orientation of phyllosilicates, primarily muscovite. This schistosity may be S2 as defined south of the Cream Valley fault. S2(?) is deformed by a second set of shear surfaces termed extension crenulations (Platt and Vissers, 1980) or normal slip crenulations (Dennis and Secor, 1987). These, in turn, are affected by a third set of shear bands. The dextral slip on the latest two s-surfaces suggests a genetic relationship between them. The orientation of the crenulation surfaces implies southeast over northwest transport.

STOP 5: PETERS CREEK SCHIST

LOCATION: Coatesville 7 1/2' quadrangle. Exposure here is afforded by both road and railroad cuts. Parking is limited to a narrow pullout on the north side of the roadway just east of the road cut. Safety is a concern at both exposures. The outcrop along the road is situated at the crest of a rise. Thus, traffic monitors posted at each end of the outcrop are recommended. The railroad tracks are active. The narrow, canyon-like cut through bedrock leaves little room for geologists.



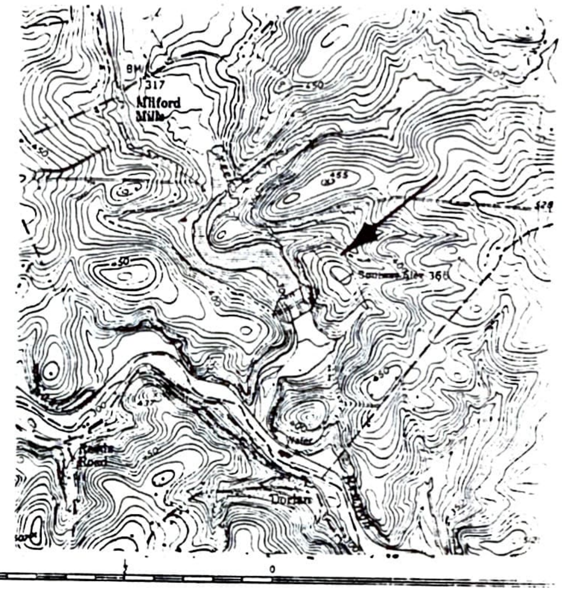
GENERAL STATEMENT: The rock here is typical of the Peters Creek schist in this portion of the Piedmont. Although the Cream Valley fault is not mapped this far to the west, preliminary indications based on rock fabric and deformational style suggest that its trace be extended westward. If the fault can be documented in this area, this exposure probably lies very close to the fault in the footwall block.

LITHOLOGY: The Peters Creek is a fine to medium grained quartz-rich schist. Minerals present include garnet, chlorite, biotite, muscovite, and quartz. Feldspar is rare; magnetite is ubiquitous. Alteration of garnets to biotite and/or chlorite around rims and in fractures suggests that the occurrence of retrograde metamorphism.

STRUCTURE: Aspects of the structural relationships observed both north and south of the Cream Valley fault farther to the east are present in this outcrop. F3 structures are present, including cross cutting relationships distinguishing F3a through F3c, at approximately the midpoint of the exposure along the road. Evidence of ductile shear in the form of mesoscopic mica fish occurs on the western end of the road cut.

STOP 6: META-VOLCANIC ROCKS (AMPHIBOLITE GRADE GNEISSES)

LOCATION: Downingtown 7 1/2' quadrangle. This stop is located at the spillway to Marsh Creek Lake. Access for this trip is along a State Park road normally blocked to vehicular traffic. Those using this guide at a later time should leave Pa. 282 at Dorlan by turning north on Dorlan Mill Road to cross over the East Branch of the Brandywine Creek and proceeding about a quarter of a mile up the hill to the northeast. Vehicles may be parked on the north side of the road taking care to permit access to the blocked road for service vehicles.



GENERAL STATEMENT: The whole rock, major element, chemistry of the gneisses outcropping in the spillway shows them to exhibit the calc-alkaline trends of the basalt-andesite-dacite-rhyolite series of the Cascades and Aleutians.

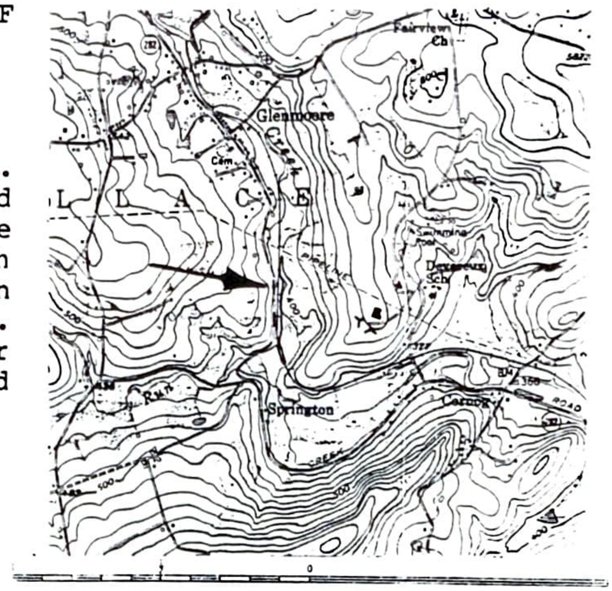
LITHOLOGY: Rock types vary from felsic and intermediate amphibolite grade gneiss to banded mafic gneisses (amphibolites).

AMPHIBOLITE FACIES:	Qu	Kf	Pl	Hy	Au	Hb	Ga	Bi	Mu	Ep	Gr
Felsic gneisses	XX	+/-	XX			Tr		XX	XX	XX	+/-
Intermediate gneisses	XX		XX			XX	Tr	XX	XX	XX	
Banded mafic gneisses	+/-		XX	+/-	+/-	XX	+/-	+/-	+/-	Tr	

Qu = quartz; Kf = potassium feldspar; Pl = plagioclase; Hy = hypersthene; Au = augite; Hb = hornblende; Ga = garnet; Bi = biotite; Mu = muscovite; Ep = epidote; Gr = graphite
XX = present in essential amounts; Tr = present in trace amounts;
+/- = may or may not be present

STRUCTURE: Folding is most easily seen in the amphibolites which contain sufficient mafic layers to highlight the deformation. Refolded isoclinal folds are the norm; the west wall of the spillway displays one very open fold.

STOP 7: HONEY BROOK ANORTHOSITE MASSIF



LOCATION: Wagontown 7 1/2' quadrangle. This cut along an abandoned railroad right-of-way is not visible from the road. Less than one-half mile south of Glenmoore, a municipal park lies on the east side of State Route 282. Park in the lot and walk 100 feet or so south along the abandoned railroad right-of-way.

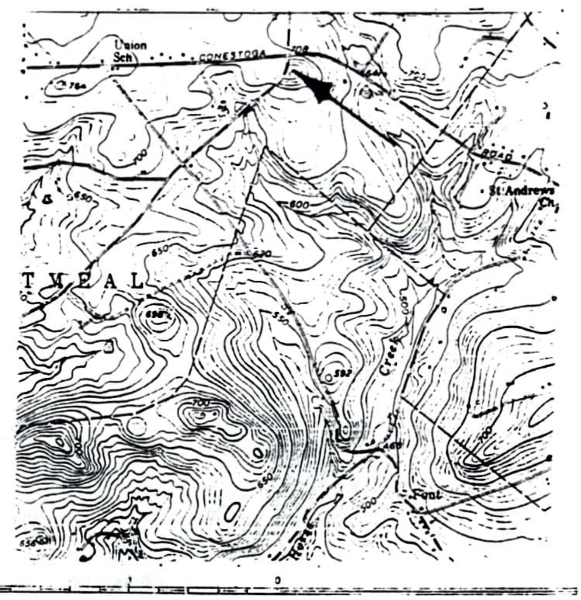
GENERAL STATEMENT: The whole rock, major element, chemistry of these anorthosite suite rocks shows they exhibit the same differentiation trend as the Morin anorthosite suite of Canada in particular and other Canadian anorthosite suites in general. Though Robelen (1968) thought the massif was concentrically zoned with anorthosite in the core and hornblende gabbro on the perimeter and intermediate types in between, recent work indicates the mafic varieties occur in stringers and screens swirled about in the massif.

LITHOLOGY: Rock types vary from anorthosite through leuco-hornblende gabbro to hornblende gabbro. Anorthosite (greater than 90% plagioclase, the remainder being hornblende and clinopyroxene) with scattered garnet and rare allanite is found in this outcrop.

ANORTHOSITE SUITE:	Pl	Hy	Au	Hb	Ga
Anorthosite	XXXX		+/-	X	Tr
Leuco-hornblende gabbro	XXX	+/-		XX	+/-
Hornblende gabbro	XX		+/-	XXX	

Pl = plagioclase; Hy = hypersthene; Au = augite; Hb = hornblende; Ga = garnet
X = present in essential amounts; No. of X's = relative abundance
Tr = present in trace amounts; +/- = may or may not be present

STOP 8: CHARNOCKITES



LOCATION: Downingtown 7 1/2' quadrangle. This road-cut in the charnockites lies just south of Pa 401 about 1 1/4 mile northwest of Ludwig's Corner (intersection of Pa 401 and Pa 100) on Fairview Road. Traffic is surprisingly heavy here. The prudent leader will post road guards at each end of the cut.

GENERAL STATEMENT: The whole rock major element chemical analyses combined with petrographic modal analyses demonstrate these granulite grade gneisses belong to the charnockite family. Using the igneous terminology of Streckeisen, 1974, they are properly termed farsundites and mangerites; using metamorphic terminology of Winkler, 1979, they are charnockitic granolites and hypersthene perthiclase granolites. There is considerable debate in the literature and no agreement as to the protolith for charnockites. These rocks are intruded by the anorthosite massif and overlain by the amphibolite grade gneisses of the calc-alkaline volcanic suite. It is assumed they represent the primordial country rock of the Honey Brook Upland.

LITHOLOGY: The rock types found in this outcrop consist of felsic granulite grade gneisses (charnockites); some massive, others faintly foliated, some quite coarse. The outcrop is cut by one diabase dike whose minerals are highly altered to greenschist assemblages. Such dikes have traditionally been assigned a Precambrian age, but they could be late Precambrian through early Ordovician.

GRANULITE FACIES:	Qu	Mp	Pl	Hy	Au	Hb	Ga	Bi	Gr
Charnockites	XX	XX	XX	XX				Tr	+/-
Mafic gneisses	XX	XX	XX	+/-	+/-	XX	Tr	Tr	

Qu = quartz; Mp = mesoperthite; Pl = plagioclase; Hy = hypersthene; Au = augite; Hb = hornblende; Ga = garnet; Bi = biotite; Gr = graphite. XX = present in essential amounts; Tr = present in trace amounts; +/- = may or may not be present

STRUCTURE: A few sites along the west wall contain sufficient mafic minerals to allow the eye to discern rather open folds.

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SEA-LEVEL RISE, COASTAL EROSION, AND GEOLOGY OF THE DELAWARE AND N. MARYLAND ATLANTIC COASTS

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The Atlantic coasts of Delaware and northern Maryland have been heavily studied by a number of coastal geologists for many years. The modern facies distribution patterns, the stratigraphy, and the physical processes which control the geologic history of the area are as well understood here as anywhere else in the world. Although this trip visits only the Atlantic coast of the states, the development of the Delaware Bay estuary plays a crucial role in the geologic history of the region, and will be briefly investigated as well.

We will visit sites which typify the littoral sedimentation patterns of the region and examine the surficial evidence which verifies the stratigraphic models proposed for this area. In addition, numerous examples of coastal erosion and inundation are found on the Atlantic coast resulting from the combined effects of sea-level rise, and artificial sediment impoundment. We will examine beach and dune loss, bridge and housing endangerment, and other local examples of problems which are also being experienced by coastal communities around the world. Economic ramifications and remediation options will be discussed.

In all aspects of the trip, the influence of sea-level will be emphasized. Predictions of accelerated rates of sea-level rise, made by various government agencies and private research institutes, bode ill for the future of coastal communities on eroding coasts. To date, the local level of planning activity meeting the challenge of rising sea level has addressed only short-term problems, with little effort expended towards planning on a longer time-scale. Federal efforts, however, have provided a framework of long-term study in an attempt to understand the effects of accelerated sea-level rise.

Part I - Should We Be Concerned About Sea-Level Rise?

Introduction-

In 1971, over three hundred thousand people in Bangladesh were killed by the storm surge from a tropical cyclone. In that country alone, nearly six million people live within three feet of sea level. Countries in the Indian subcontinent, the eastern Mediterranean, northern Europe, and other low-lying areas could be devastated by even a moderate rise in sea level. The threat of famine, disease, and loss of life due to sea-level rise in densely populated, poor nations is a reality when evacuation procedures are inadequate. In these countries, the economic impacts of sea-level rise are superceeded by concern for the protection of human life, while in the United States early warning systems and evacuation procedures are designed to prevent such catastophes. Our efforts in the face of natural disasters tend to focus on planning and remediation, through a combination of basic research, technique development, and model testing.

The phenomenon of sea-level rise is a consequence of the delicate global balance between ice and water. The ice volume in the great polar ice-caps of Greenland and Antarctica, and the water volume residing in the ocean basins are both maintained by the global climate. When the mean atmospheric temperature shifts only a few degrees, the balance of these volumes is upset. Warm the atmosphere, and the ice at the poles begins to melt. In addition, the surface waters of the global ocean expand because they are warmed as well. The melt water goes into the ocean basins and with the thermal expansion of the water column, the level of the seas begins to rise. Similarly, when the temperature drops, the polar ice caps expand and create a long-term reservoir of ice made from water that is removed from the oceans, thus, sea-level falls.

Climate and Sea level-

For at least the last one million years (probably longer), major fluctuations of sea level have occurred on nearly a one hundred thousand year cycle, with smaller fluctuations superimposed on this longer trend every forty one thousand and twenty three thousand years. These cycles of sea level are thought to reflect changes in solar radiation reaching portions of the earth due to cyclic variations in the tilt of the earth's axis. These natural cycles change the earth's climate by alternately increasing and decreasing the exposure of the northern and southern hemispheres to the sun's heat, elliciting a contemporaneous response in the position of sea level.

Another natural phenomenon at work in the climate system is the greenhouse effect. Most of the sun's radiation passes through the atmosphere and strikes the earth's surface. The surface warms to an extent which depends on the heat absorptive properties of the surface material. For instance, the oceans absorb as much as 90% of incoming heat whereas land retains only 50% or less. The heated earth surface then radiates at infrared frequencies. However, atmospheric carbon dioxide, water vapor and certain other gases may absorb the infrared radiation rather than allowing it to pass through the earth's atmosphere to space. The trapped radiation warms the atmosphere in a manner analogous to a greenhouse which uses glass panels to trap heat. Without the atmospheric greenhouse effect the atmosphere would be an average 33 C cooler than at present. Thus, there are long-term natural processes which cause variations in the climate and, therefore, variations in sea level.

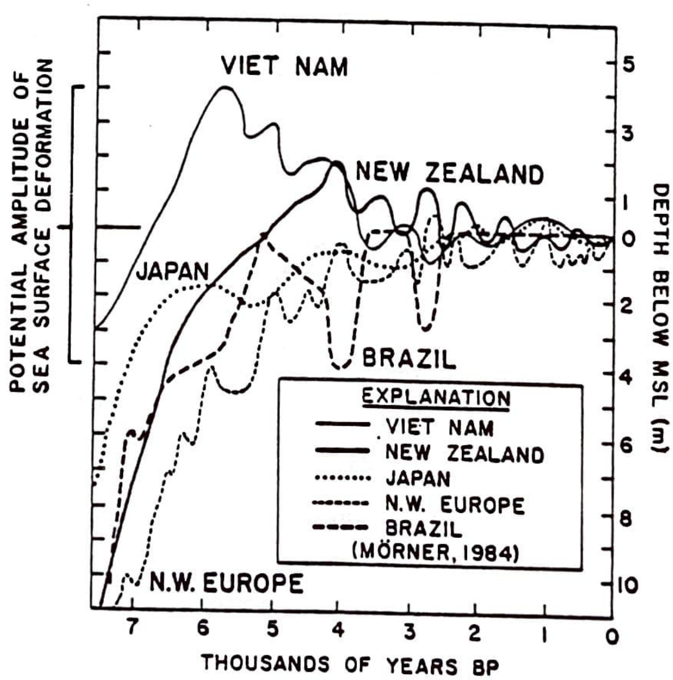
However, the relationship between sea level and climate is far more complex than it may appear to the casual observer. Indeed, simply identifying changes in the level of the world's oceans can be a very perplexing problem. As it turns out, the closer we look at sea level, the more we realize that our points of reference are moving also. That is, the continents beneath our feet are rising and falling as well. How, then, does one measure the vertical change of the ocean surface when there is no stable point of reference? Further, as we inspect the ocean surface we find that there are a maze of factors that affect its vertical position which are completely unrelated to the climate.

However, climate related factors are the most important from the perspective of long-term effects. Recent increases in concentrations of carbon dioxide and other heat-trapping gases in the atmosphere, due to industrial activities, suggest that our climate is indeed changing. Numerous predictions of global warming by governmental and private agencies, as well as unusual atmospheric phenomena (such as the Antarctic ozone depletions) point to the urgency of understanding the potential for climate change and sea-level movement.

The History of Sea Level-

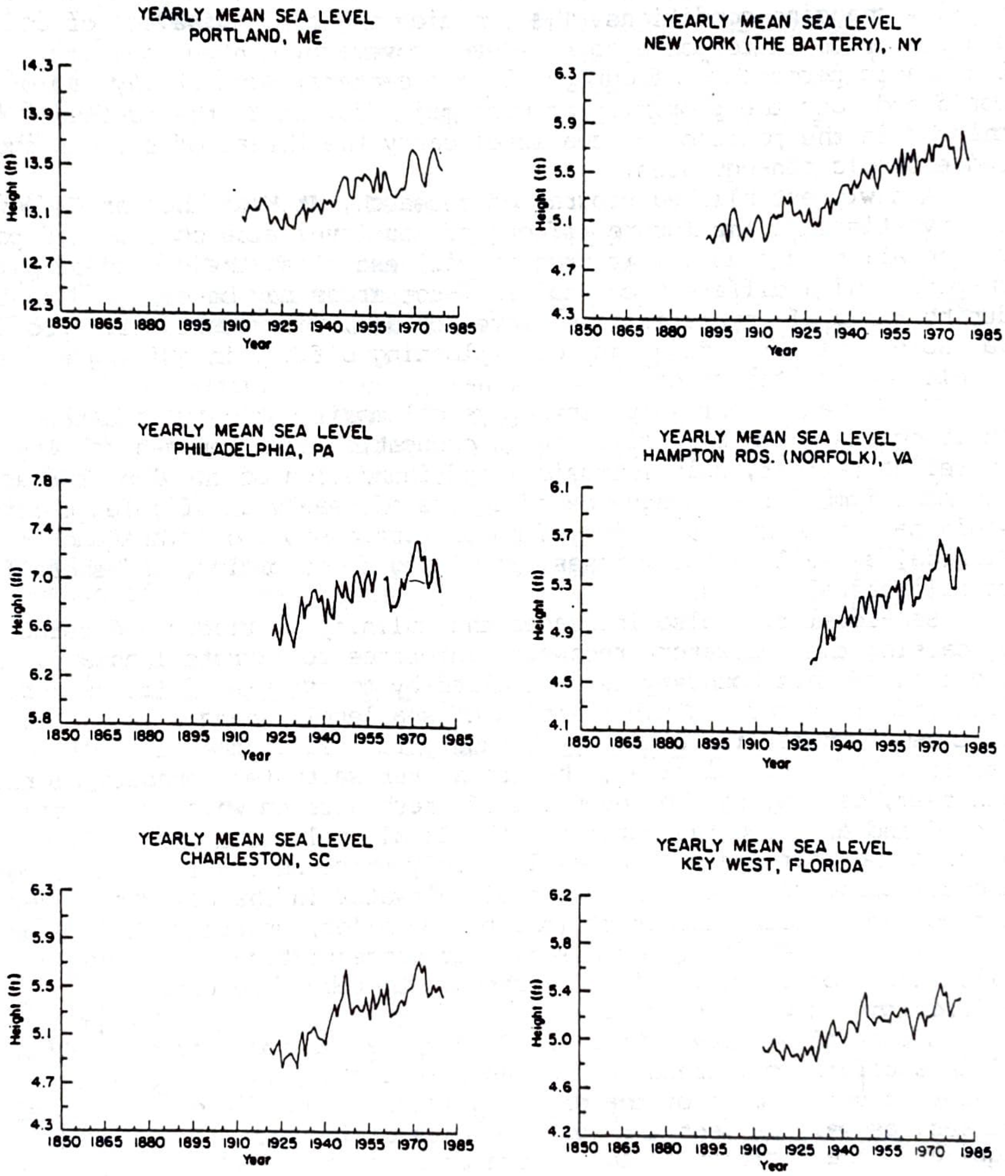
In evaluating the future behavior of sea levels and coastlines, it is instructive to consider their past histories. Although researchers cannot agree on the exact timing and elevation of former global sea levels, as figure 1 will attest, clearly, the elevation of past water levels below modern sea level (msl) changes quite substantially over time (on the horizontal axis). Here are displayed the histories of sea level from 5 different areas, over the last 7,000 years. Differences in the vertical movement of these various continental areas are responsible for the lack of agreement between the 5 histories. Although the local sea-level history at each of these sites does not describe a global pattern, these histories do illustrate that the phenomenon of sea-level change is a reality of nature.

<u>FIGURE 1 - A global survey of sea-level histories</u> (from Morner, 1984).



Along the United States east coast, work by geologists suggests that not only has sea level been steadily rising over the past 18,000 years, but that it is on the rise now. Evidence for the current rise of sea level is shown in figure 2. This figure shows a plot of yearly mean sea level from tide gauge stations located at 6 major cities, including: Portland, Maine; New York City, New York; Philadelphia, Pennsylvania; Norfolk, Virginia; Charleston, South Carolina; and Key West, Florida. It is quite evident from these graphs that the position of sea level at these cities, indeed along the entire east coast, has been rising over recent decades. The upward trend on each of the plots is a result of the increased height of the water level above some reference horizon. These measurements extend back to the early part of this century, when the data collection program first began. With the exception of some isolated cases of short duration, there has been a consistent rise in the average water level since that time.

FIGURE 2 - Recent sea-level history along the U.S. east coast (Hicks et al., 1983).



Physical Consequences of Sea-Level Rise-

Research conducted at the University of Delaware and West Chester University on the history of sea-level rise in the mid-Atlantic region, has revealed the stages of coastal evolution which produced the modern system of barrier islands, estuaries, inland bays, marshes, and capes characteristic of the coast. In addition, a separate but related program of research, also carried out at West Chester, has outlined the history of vertical movement of the east coast continental margin. In conjunction with scientists from the U.S. Department of the Interior, and neighboring universities, our work provides a description of the patterns of sea-level inundation and flooding, salt-water intrusion, and shoreline erosion that comprise the geologic history of this highly populated coast.

The tide gauge data of figure 2 indicate that the rate of sea-level rise has been increasing in recent decades, suggesting that these natural processes of environmental change may be accelerating. As the oceans rise, the shallow marine, estuarine, and coastal environments migrate landward in order to maintain their position relative to sea level. Coastal cities, transportation systems, water supplies, and waste disposal techniques have not been designed with the capability of easily adapting to such rapidly changing conditions. The dynamic, migratory behavior of coastlines and estuaries in response to sea-level movement, contrasts sharply with the static permanence of our population centers. Look at any map of the world and note the proximity of most major cities to the oceans; clearly, changes in the position of sea level carry the threat of serious social and economic consequences.

A newly established program of research, at West Chester University, is investigating the future effects of sea-level rise on selected portions of the Atlantic coast. This program will establish the degree of physical response which different coastal land-use areas may be expected to exhibit during times of accelerated sea-level change. The results will provide a valuable tool for aiding the local planning offices in guiding the economic development of the coast.

Sea-level rise results in a physical modification of coastal environments which may affect human occupation in three general ways: shoreline retreat, salt intrusion, and inundation of the land surface. The most immediate consequence of a rise of sea-level of a few meters would be permanent inundation of major portions of Louisiana and Florida, as well as the marshes, low-lying flood plains, and shorelines of all coastal states.

Sea-level rise also increases the salinity of rivers and estuaries by causing the saltwater/freshwater interface to migrate landward. The location of this boundary is controlled by the volume of freshwater flow from the land and the position of sea level. Changes in either one of these factors will cause the boundary to shift either landward or seaward. As sea-level rises, the freshwater/saltwater boundary migrates upstream, destroying the resources of freshwater on which our cities depend and altering the nature of the local ecological and environmental systems. An increase of sea level of only thirteen centimeters (five inches) could cause the intrusion of saltwater in the Delaware River as far as two to four kilometers (one to two miles) upstream. A rise of one meter (over three feet) would send salt concentrations over twenty kilometers (over twelve miles) upstream, thereby threatening Philadelphia's water supply.

A rise of sea level will also cause the salt content of Coastal Plain aquifers to increase beyond useable levels. These groundwater resources supply most of the drinking water to the cities in coastal states, as well as meet the heavy demands of industry. In coastal aquifers, the position of the saltwater wedge that underlies the less

dense freshwater is determined by sea level. Therefore, a rise of sea level will result in a rise of the entire groundwater table, bringing the level of the saltwater to within reach of fresh water wells. Overpumping of coastal aquifers also has resulted in salt intrusion, a situation which will be exacerbated by sea-level rise.

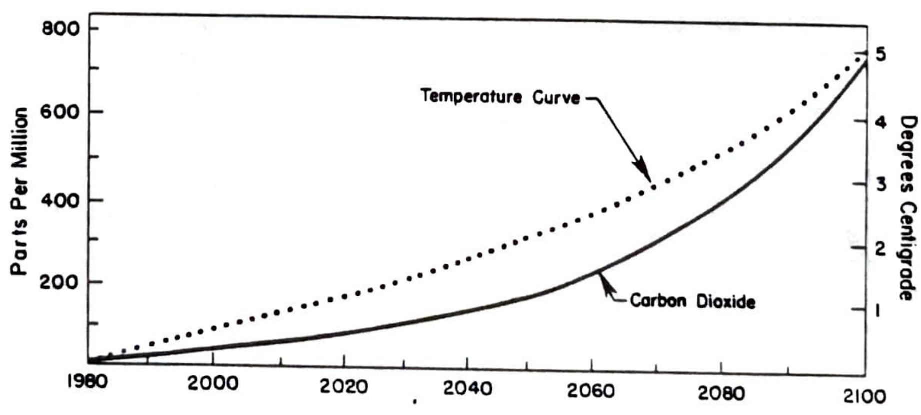
In addition to the serious problems accompanying inundation, many coastal areas will be threatened with another physical consequence of sea-level rise: coastal erosion and increased storm damage. The low atmospheric pressure and high winds which characterize hurricanes and other storms result in temporary increases in the water level by as much as several meters. The high energy of the waves generated by these conditions removes the sands and gravels of beaches and headlands to points offshore, where the water is deeper and the sediments experience less turbulent energy. After the storm has waned, much of this material is beyond the reach of the beach-building, lower-energy waves exisiting under normal conditions. The resulting erosion is permanent testimony to the rapid landscape alteration which typifies the shore zone. A rise in sea level moves the corridor of storm damage landward, and in the low relief topography of the coastal plain, a vertical sea-level rise of one meter will translate to a lateral shift of many tens to hundreds of meters. The fragile barriers to storm damage which protect population centers such as Boston, Providence, Atlantic City, Ocean City, Virginia Beach, and Miami Beach will be quickly overwhelmed by the new storm tracks.

Predictions of Future Sea-Level Rise-

Several reports by the U.S. Environmental Protection Agency, Office of Policy and Resource Management, and the National Research Council, Carbon Dioxide Assessment Committee have concluded that atmospheric carbon dioxide levels will most likely double by late in the next century and cause an increase in global temperature of between 1.5 C. and 4.5 C. In addition, several other gases besides carbon dioxide (chlorofluorocarbons, nitrous oxide, and methane) are noted to have climatic effects which would cause warming more rapidly than CO_2 alone.

Tidal gauges at various locations on the world's coasts have suggested that a global rise of ten to fifteen centimeters has occurred in the last century. At least part of this rise has been explained by the warming trend of 0.4 C of the last century and the resulting expansion of the water column, the remainder may be due to some ice conversion to sea water.

FIGURE 3 - Carbon dioxide content and temperature history predictions.



Predictions by the Environmental Protection Agency have determined that global sea level will almost certainly rise in coming decades with a likely rise of between 144 centimeters and 217 centimeters by the year 2100. A rise as low as 56 centimeters or as high as 345 centimeters by 2100 cannot be ruled out. The report also concluded that along most of the Atlantic and Gulf coasts of the United States, the rise will be 18 centimeters to 24 centimeters more than the global average. Table 1 shows these predictions

TABLE 1

PREDICTED FUTURE GLOBAL SEA-LEVEL RISE IN CENTIMETERS
(from the U.S. Environmental Protection Agency)

Estimate Scenario	Year				
	2000	2025	2050	2075	2100
High	17.1	54.9	116.7	211.5	345.0
Mid-High	13.2	39.3	78.9	136.8	216.6
Mid-Low	8.8	26.2	52.6	91.2	144.4
Low	4.8	13.0	23.8	38.0	56.2

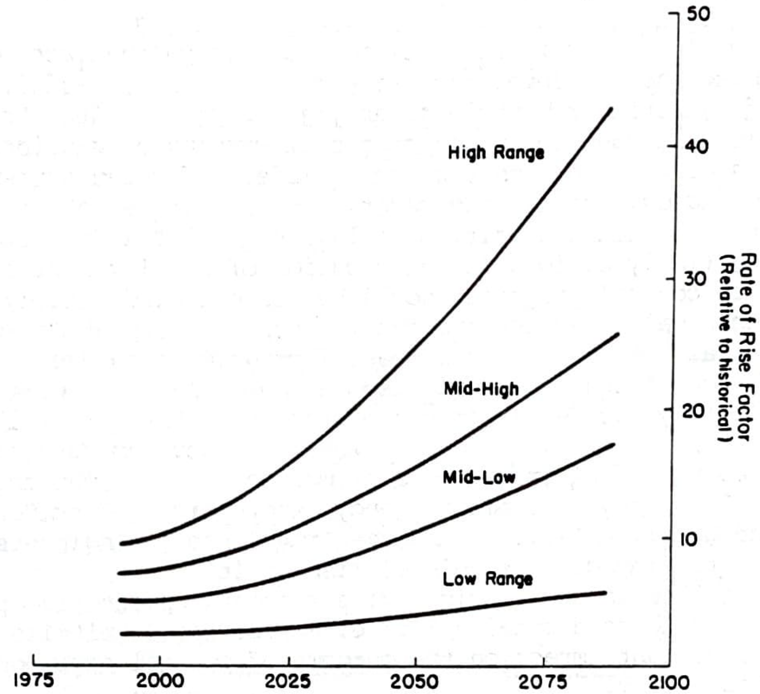
The authors of the E.P.A. report feel that the actual amount of sea-level rise will fall in the mid-range of these predictions rather than in the extreme low or high ranges. Calculations using the data of table 1 reveal that, regardless of the estimate scenario, the rate of sea-level rise accelerates through the period of study. Even in the predicted low range, sea level will rise twice as fast as the historical rate of ten to fifteen centimeters per century, over the next fifteen years. The period 2000 to 2025 shows three times the historical rate of rise, while the high range rate from the year 2075 to the year 2100 is 5.3 centimeters per year, over forty times the historical rate.

The Call For Action-

As figure 4 illustrates, the rate of sea-level rise may accelerate quickly in coming years. This is a cause of concern as the efforts of coastal planners and city councils, burdened with inadequate budgets, to address the current rise of sea-level and it's associated problems, have been hesitant and slow. With higher rates of inundation and erosion predicted over the next century, the cushion of response time on the part of our civic leaders is diminished.

Unfortunately, the longer that remediation efforts are avoided, the greater the damage that is possible in a single major storm. One characteristic of nature that is recognized by scientists is the tendency for long-term averages to be composed of punctuated events of high intensity. In the case of coastal evolution and environmental migration, long term rates of change and movement will be manifested as short periods of great alteration separated by long periods of little activity. In other words, a few decades in which the erosion and inundation problems are minor concerns will be followed by an intense storm of only a few days duration in which great alterations to the

FIGURE 4 - Predictions of the increased rate of sea-level rise.



coastal system are made. In the minds of those whose job it is to plan for the future, the memory of past major storms quickly becomes faint with the routine concerns of running a city, and thus, many of our coastal communities lie unprepared for the next major event of natural change.

The costs associated with the consequences of rising sea level could be very high if the issue is ignored. The E.P.A. predictions suggest that the worst effects will not be felt until the year 2025. However, the current crisis of erosion affecting low-lying areas and beach resorts will only worsen to the point where beach protection will be abandoned in favor of protecting the very infrastructure of the cities. Buildings could be destroyed, government subsidies to victims of natural disasters will become very costly, roads, bridges, docks, and navigational aids will need to be reconstructed, drainage systems will need to be redesigned, and basement flooding will be a common hazard, expensive desalinization facilities will be constructed, water intakes relocated, and municipality and township riparian rights renegotiated. Furthermore, decisions made in the next decade will significantly influence the extent of damages, and cost levels from sea-level rise in the next century.

Thus far, the response of the general public to scientific predictions of sea-level rise and it`s physical consequences has contained two major messages: first, estimates of sea-level rise must be improved with the goal of presenting more narrowly specified predictions and a higher level of accuracy; and second, even then it will be difficult to produce a proper response from concerned parties.

Several recommendations have been forwarded by researchers and policy planners concerning the allocation of future efforts in this arena.

1. Federal research on the physical, environmental, and economic impacts of sea-level rise should be substantially expanded. Present studies have provided only rough estimates of some of the physical and economic impacts of sea-level rise and the value of preparation. However, support of this kind must be joined by a concerted effort on the behalf of experts in the private sector, academia, and local governmental agencies.

2. Federal support for scientific research on the rate of future global warming and sea-level rise should be greatly expanded. The benefits of this research would clearly justify the costs. Areas of concentration include the impact of global warming on glaciers, sources and storages of minor greenhouse gases, models of ocean currents, models of the frequencies, tracks, and severities of tropical storms and northeasters. Coastal communities would save billions of dollars by implementing timely actions in anticipation of sea-level rise.

3. State coastal programs should be strengthened. Often, the required technical expertise and funding exists only on the state level.

4. Federal, state and local coastal programs should consider the impacts of accelerated sea-level rise in their planning. Communities should explicitly decide the amount of resources they are willing to invest to resist erosion, and higher levels of government should educate the public about the ultimate costs of maintaining current shorelines. The Federal Emergency Management Agency, the National Park Service, the Fish and Wildlife Service, and the Army Corps of Engineers should all consider the impact of sea-level rise on it's programs.

5. Coastal engineers should revise standard engineering practices to consider accelerated sea-level rise. Future sea-level rise is likely to have an important impact on the outcome of coastal engineering decisions made today.

6. Research into the most effective ways of communicating risks and motivating effective responses should be undertaken. An informed public is not always a responsive public.

7. A well-respected group of coastal engineers, coastal geologists, planners, and other decision makers should conduct an independent review of the necessity of planning for sea-level rise. The gap between practitioners and researchers, groups with potentially differing incentives, would be bridged by such a review panel.

The potential for disaster along todays shore zone needs to be met with planning based on consideration of the historical trends of coastal evolution, predictions of accelerated sea-level rise, and knowledge of changes in land-use patterns resulting from a rapidly increasing population. Preparation of this sort may be considered esoteric by local government planning offices because the warning signs of climate change and sea-level rise are subtle. In addition, coastal planners feel that their options are limited in planning for future sea levels due to the permanence of urban centers, a problem which needs to be directly addressed by research. The onus of preparing for the future therefore falls upon the research community to lay the groundwork and build the template of fundamental knowledge concerning the behavior of the coastline under accelerated rates of sea-level rise.

Part II - Geologic History of the Region

Introduction-

Regionally extensive core data, seismic-reflection profiles, and paleogeographic reconstructions provide a detailed history of the last 10,000 years (the Holocene) of sea-level rise, coastal inundation, and sedimentation within the Delaware estuary and along the Atlantic coast. Figure 5 presents a synopsis of the region, including: 5A, showing the Delaware and Maryland coasts in a regional geographic setting; 5B, providing the sea-level history of the Delaware coast, based on in-place peats dated by radiocarbon and sampled by vibracore; 5C, showing a topographic map of the depth to the pre-transgression erosional surface; 5D, the bathymetry and local geography; and 5E, which illustrates the generalized environments of deposition in the region.

Flooding Patterns-

At the close of the most recent glacial maxima (18,000 years ago), sea level began rising in response to climate change and atmospheric warming. The position of mean high water transgressed the modern estuarine platform, shifting the position of environments of deposition, and permanently altering the geomorphology. The geomorphic configuration of the pre-transgression surface was the result of a deeply entrenched fluvial system which drained the region during the late stages of glaciation (see figures 6 and 9). An important feature between the transgressing marine system and the retreating fluvial system is the estuarine turbidity maximum. This zone is characterized by the partial deposition and partial dispersal of the sediments that are delivered by the land-based runoff to the tidal circulation of the estuary. The deposition of these fine-grained sediments in various estuarine and coastal environments of the region results in the complex stratigraphy which records the geological history of the area (figure 9).

The position of the estuarine turbidity maximum depocenter migrated to the northwest across the estuarine platform at a rate determined by the rate of sea-level rise, and along a path determined by the topography of the pre-transgression surface.

By 12,000 years ago this depocenter was located on the modern continental shelf, to the southeast of the modern baymouth, and was an important influence in the early history of the Atlantic coast. By 10,000 years ago, the turbidity maximum depocenter had relocated to approximately the position of the modern baymouth, resulting in sediment dispersal along the axis of the side valleys which were tributary to the ancestral Delaware River in this area. The Atlantic coast was removed from the flux of fine-grained materials supplied by the turbidity maximum, and as a result, open water lagoons began to develop with the rising sea level by 8,000 years ago.

On the estuarine coast, a shoreline consisting of exposed tidal-wetland muds occupied the widened tributary mouths, and extended laterally around the flooded paleo-interfluves to adjacent confluence sites during the period 7,000 years to 5,000 years. This development was contemporaneous with the migration of sea level past Egg Island Point and into the more restricted reaches of the upper estuary. At the same time, the southeast portion of the estuarine platform (the Delaware coast) had widened sufficiently to allow the heightened wind-wave activity resulting from the increased fetch, to modify the characteristics of the southern shore and cause the erosion of the existing deposits. Between 5,000 years and 3,000 years, the Maurice

FIGURE 5 - Regional geology and geography.

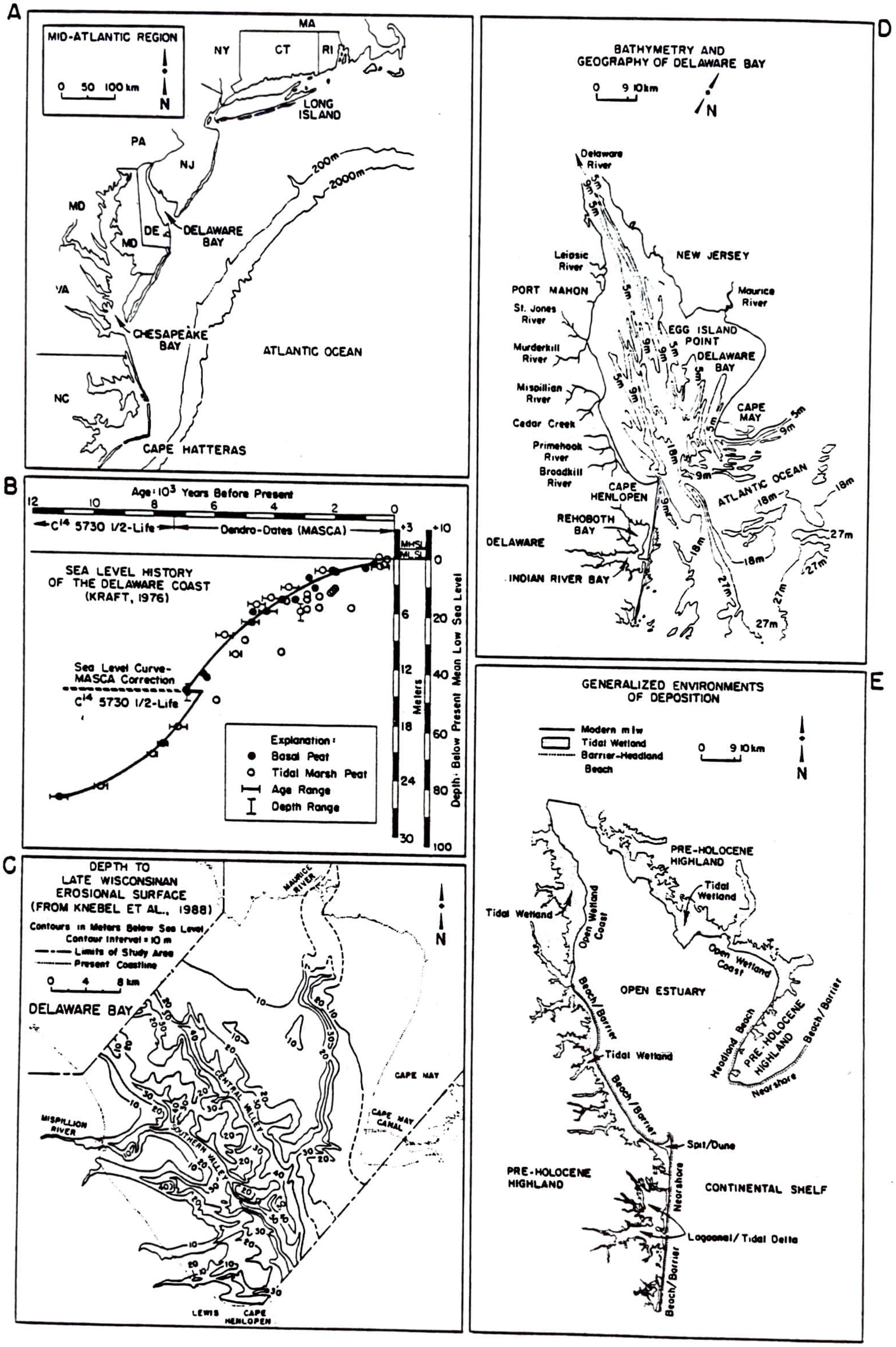
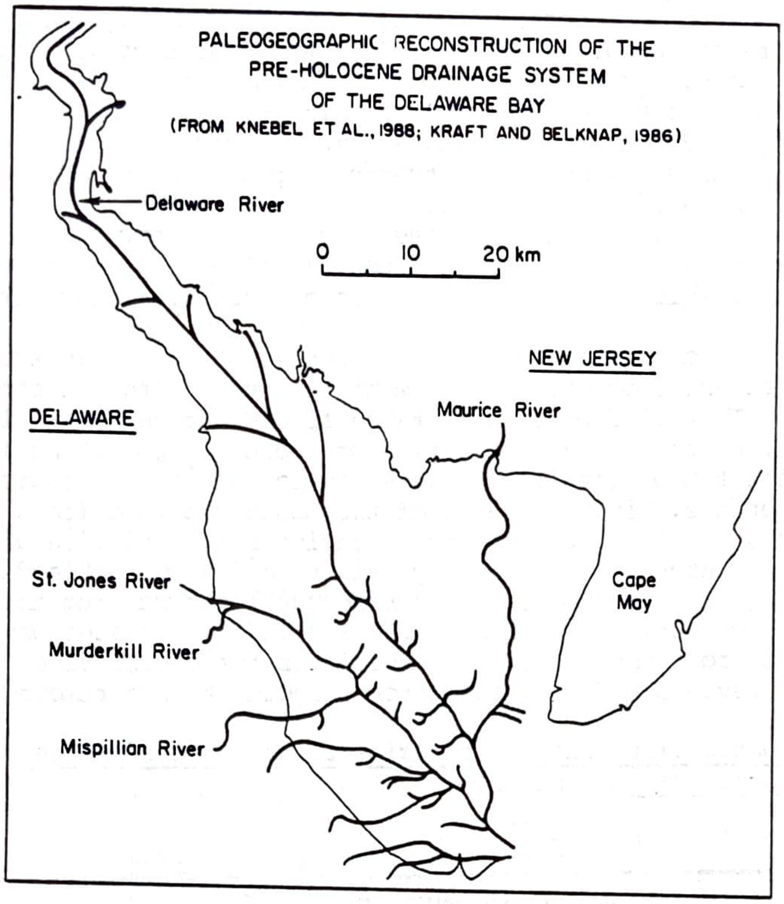


FIGURE 6 - Reconstruction of the pre-Holocene drainage.



River and the St. Jones/Murderkill system were experiencing significant inundation and headward retreat, while the Port Mahon area was still in the early stages of flooding. By 3,000 years to 1,000 years ago, sea level had moved to the Piedmont margin and was confined to a narrow channel, dictated by the topographic conditions.

Coastal Evolution-

The changing position of sea level influences the set of processes and the flow of sediments which are active on the estuarine coast in a continuous fashion. As a result, the coast is constantly adjusting to new controlling conditions, and the adjustment describes a continuum between the periglacial/fluvial system and the completely inundated estuarine floor.

Initially, a simple rise in the water level results in flooding of the land surface and attendant deposition of muds and organics. Tidal circulation controls the development of the coast at this early stage. Fine-grained tidal wetlands extend across the pre-transgression surface creating a mud coast populated by tidal vegetation exposed to the low-energy, open water environment. At first, the muddy vegetated coast is frequently interrupted by gravelly highlands, but soon, the high rate of sediment influx allows deposition at the tributary mouths and up onto the flooded highlands. The muddy coast extends and connects laterally, creating long expanses of shoreline consisting exclusively of tidal wetlands.

As the estuary broadens with continued inundation, the increasing fetch results in a high level of wind-wave energy at the shore, and the exposed tidal wetlands and occasional highlands develop migrating washover barriers and headland beaches. As these coarse-grained deposits move landward with each new storm, subtidal flats develop along the estuarine margin which may extend well into the open estuary. Eventually, these muddy surfaces which are the degraded remnants of former littoral sequences, collect estuarine deposits consisting of fine sands and interlaminated sand and mud.

In this fashion the coast undergoes a series of changing conditions, each with a unique set of depositional environments and incident energies, which describe a gradational evolution to modern conditions.

Figure 7 is a schematic block diagram representing the interaction of the modern processes of coastal sediment transport with the eroding Holocene strata. This illustration is taken from Kraft and John, 1976.

Figure 8 illustrates the time series of evolution resulting in the modern coast. The top of the figure shows development of the incised pre-transgression surface. With the onset of the constructive deltaic phase of sedimentation, tidal circulation accompanying sea-level rise distributes fine-grained sediments up the tributary valleys and tidal wetlands aggrade. With the migration of the estuarine turbidity maximum through the region, open estuarine conditions prevail, and the greater wave energy begins to erode the coast. This initiates the destructive deltaic phase, and the previously deposited littoral sediments are removed.

FIGURE 7 - Schematic illustration of facies relationships on the Atlantic coast.

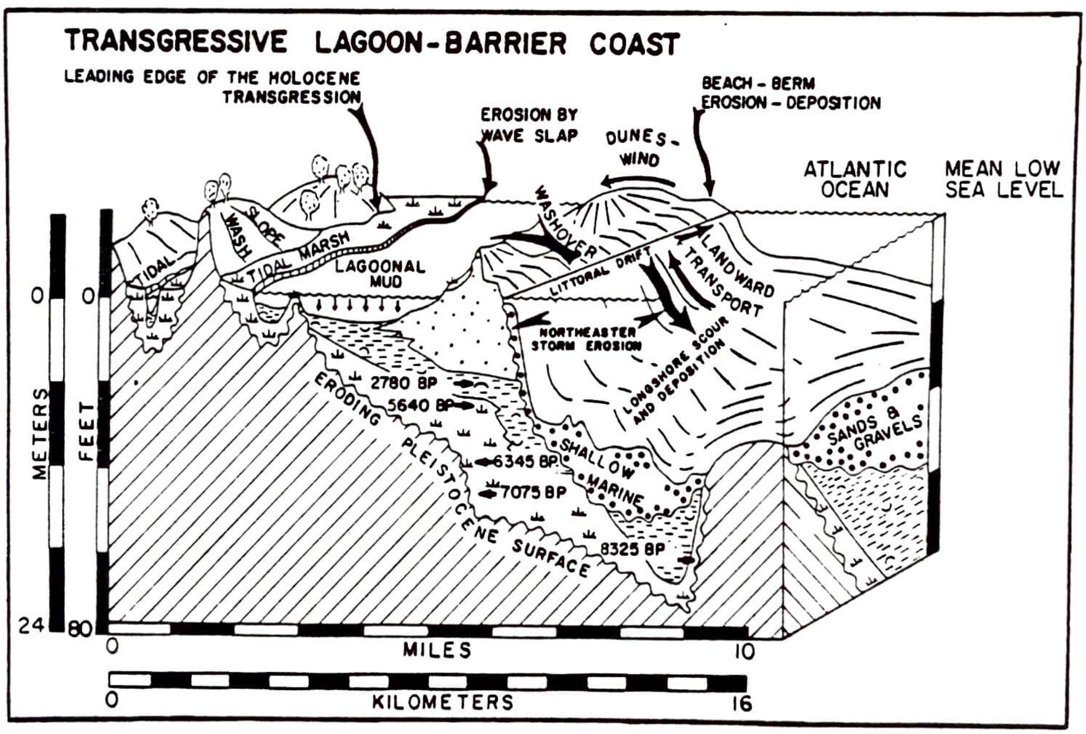
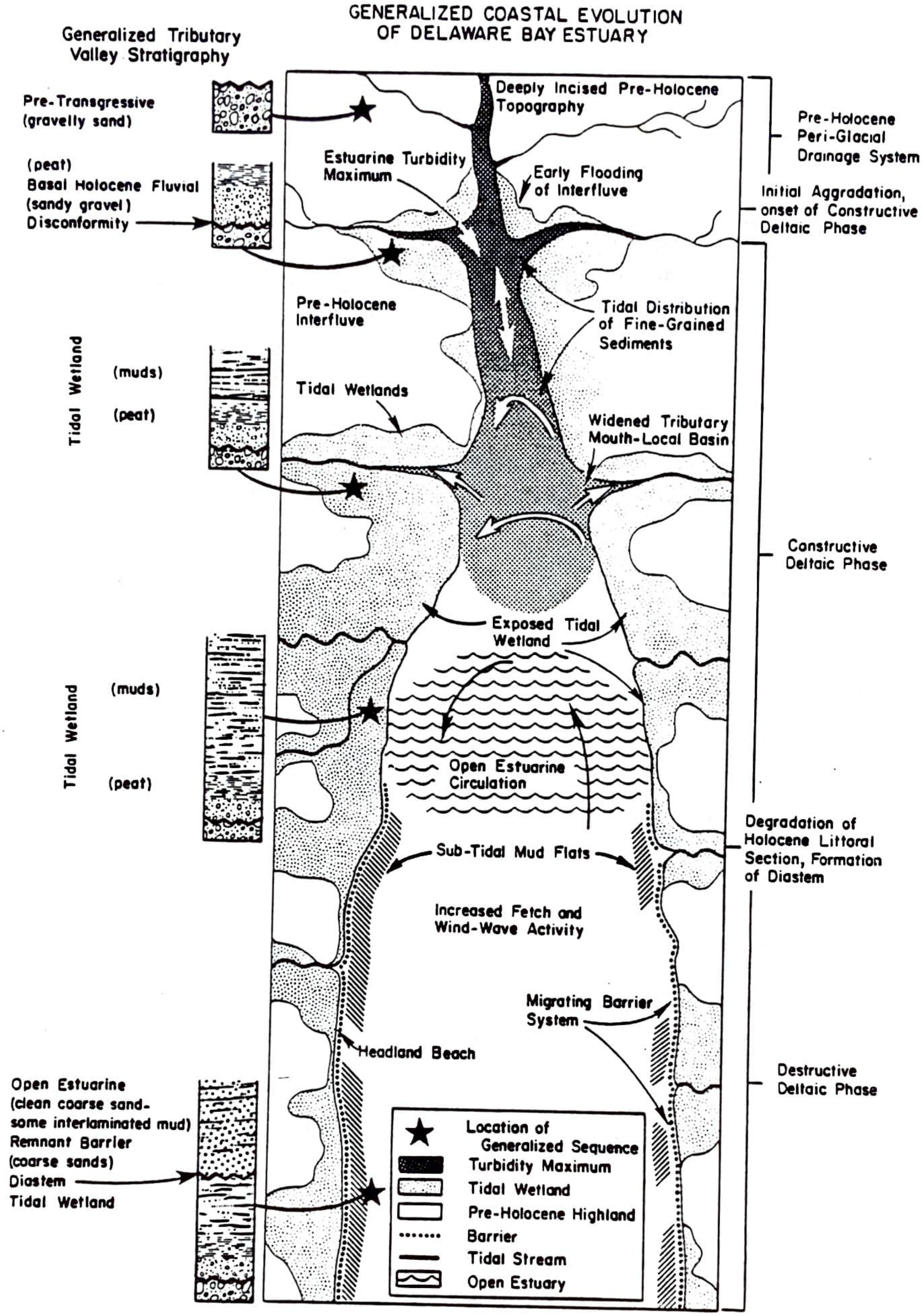


FIGURE 8 - Evolution of the Delaware estuary.



FIELD TRIP ROAD LOG

Depart West Chester University at 7:30am

STOP 1: Ocean City Inlet - North Jetty

-Located at the artificial southern terminus of a longshore drift system, the construction of this jetty, in order to stabilize the inlet, has prevented sediment from reaching the northern shore of Assateague Island. As a result, natural washover processes have caused a downdrift offset of over 1km. The rapid migration of the barrier island threatens to cut off the northern entrance to Chincoteaque Bay, a major commercial fishery. To the north, the jetty has allowed an economically important beach to exist in the face of sea-level rise and storm onslought.

STOP 2: N. Ocean City Beach

-Only a mile to the north, the beach is a narrow strip of ephemeral sand, frequently overwashed by high tide, and easily eroded by high wave events. Construction of houses, beach-front hotels, and other multi-unit structures on the former dune line has destroyed one of the most valuable natural sand resources available to a beach. Offshore winds are no longer able to maintain a stable volume of beach material by moving sand from the dune field to the beach, and the beach erodes quickly and permanently in response.

STOP 3: South Bethany/Fenwick Island

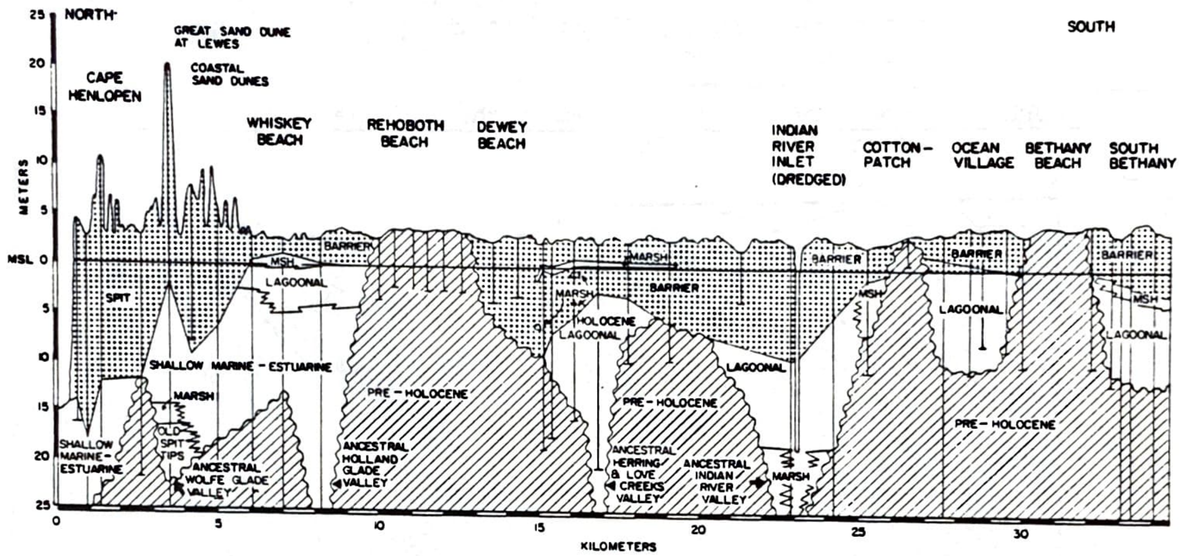
-To the south, a semi-natural coast extends for several miles. This stretch of shore consists of a wide, sugar-sand beach, nourished from the west by a vegetated dune field, and from the south and north by adjoining beaches. To the north, construction on the dune field has caused severe beach erosion to occur, resulting in a line of houses which are awash at high tide every day. Storm damage is extensive in this area and reaches back through several lines of houses, destroying the roads of the neighborhood, ripping out plumbing, flooding the sewage system, and often completely inundating the narrow barrier island under a meter or more of water. During the 5-day storm of 1962 this area was under a 3m. surf zone. Marsh peats frequently crop out along the beach here, indicating the extremely eroded condition of the sand resources (figure 11).

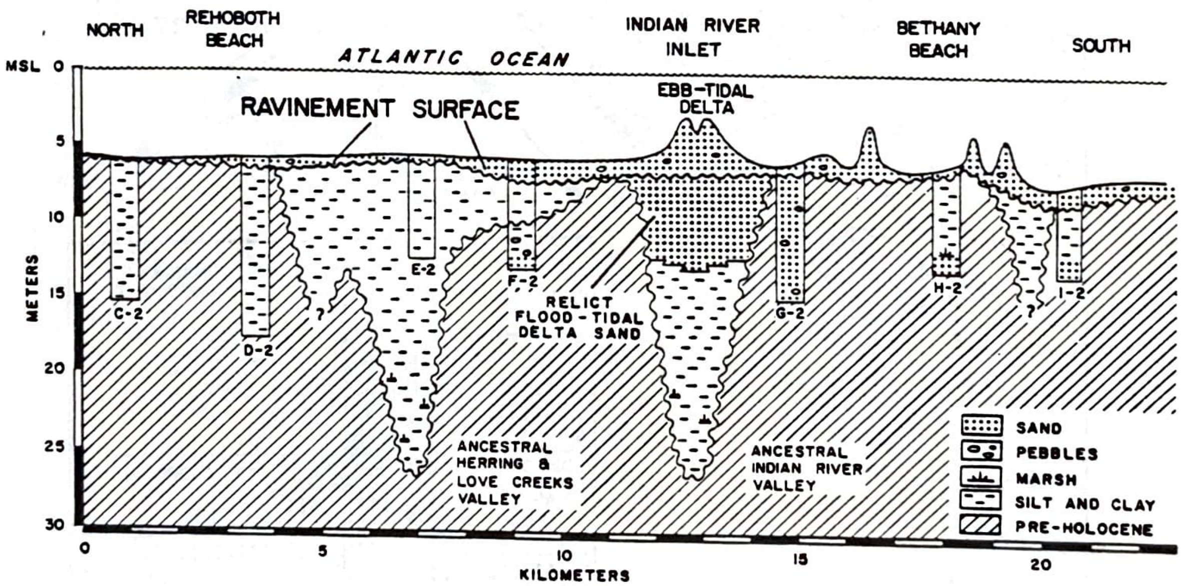
STOP 4: Indian River Inlet

-A migrating inlet has existed in this area for a few thousand years. Periods of shoaling, closure, and movement caused the Army Corps of Engineers to stabilize the inlet in 1938-40 with two shore normal rock jetties. These structures have interfered with the longshore drift system to the extent that severe erosion of the beach to the north of the inlet due to sand impoundment on the south jetty threatens the bridge access,

and Route 1 Highway. Additionally, miscalculation of the natural tidal prism through the inlet lead to construction of an over-narrow channel between the jetties. The high velocity tidal flow that resulted has scoured the channel to over 30m. deep in some places, and threatens the very footings of the bridge. The net northward longshore drift in this area is approximately 80,000 cubic meters per year. Following construction of the jetties, the southern shoreline accreted 2.7m/yr, and the northern shoreline eroded 4.1m/yr. A permanent sand bypassing plant was approved in 1986.

FIGURE 9 - Coast parallel cross-sections of the Atlantic coast (Kraft et al., 1987).





STOP 5: Rehoboth Bay Barrier/Lagoon System

-From atop the bridge, one can view the numerous sedimentary depositional environments associated with the Rehoboth Bay lagoon and baymouth barrier island (figure 10), including: the inner continental shelf, the surf zone, beach and foreshore, dune field, washover fans, backbarrier marsh, lagoon, fringing marsh, abandoned flood tidal delta, and various tidal channels. This entire complex migrates landward and upward in space and time onto the Coastal Plain by occupying the incised drainage system of the pre-transgression surface. This lagoon actually consists of Indian River Bay, which floods the main axis of the ancestral Indian River Valley, and Rehoboth Bay which floods a number of stream valleys from the paleo-watershed system (figure 9).

FIGURE 10 - Model of sediment movement through the coastal zone (Kraft et al., 1987).

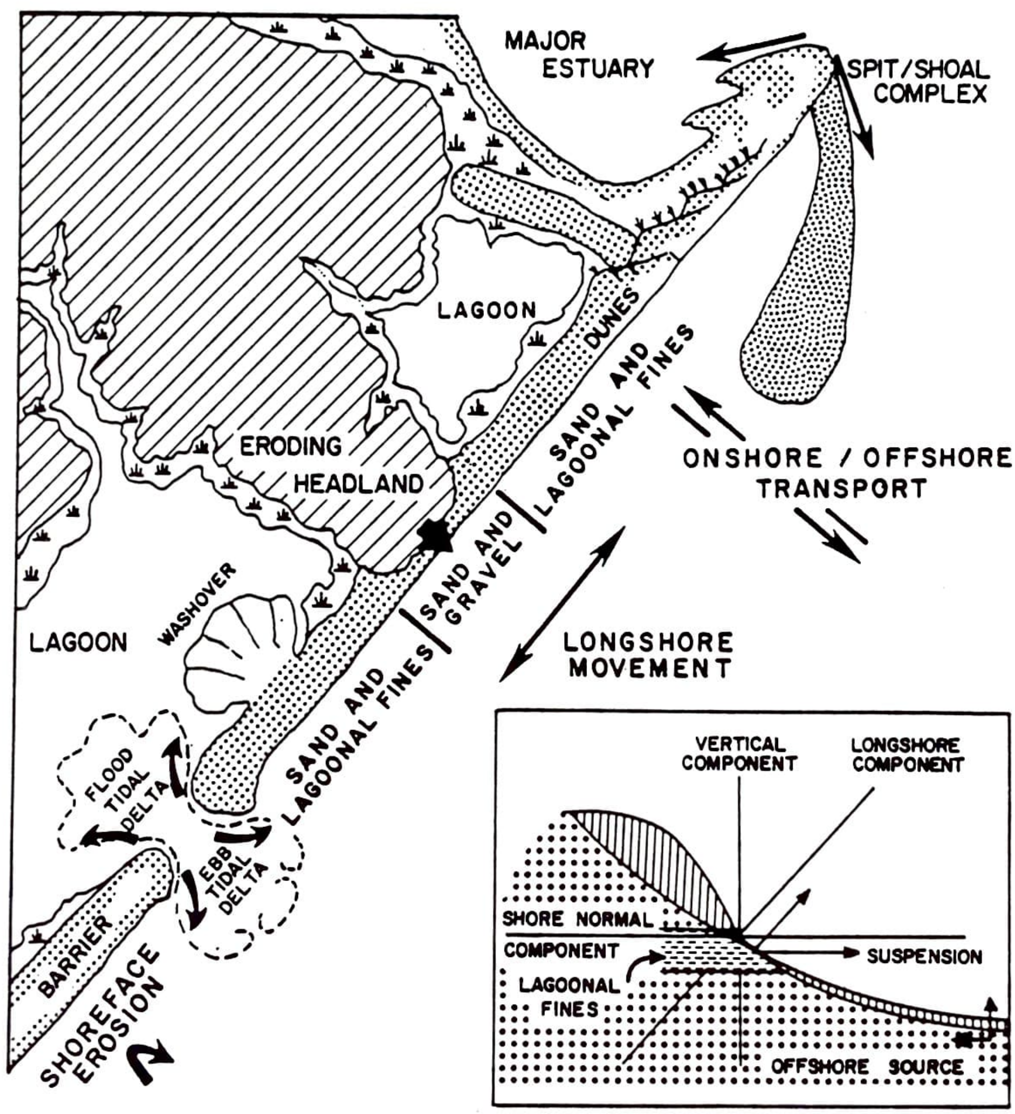
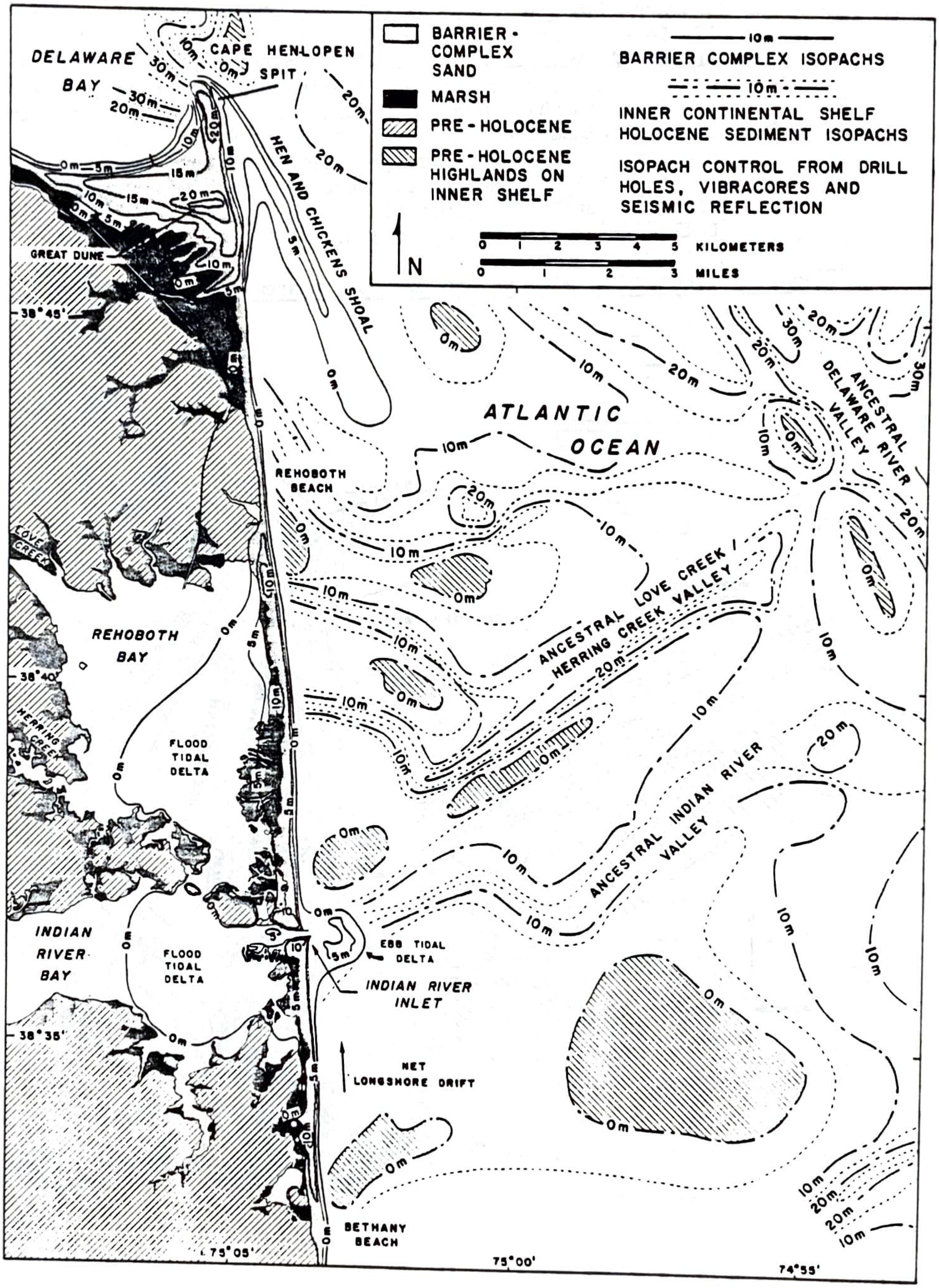


FIGURE 11 - Isopach map of Holocene sandy sediments (Kraft et al., 1987).



STOP 6: The Spit System at Cape Henlopen

-The northern terminus to the longshore drift system along this coast is Cape Henlopen, an accumulation of sand characterized by several geomorphic elements shown in figure 12. Lewes Creek Marsh is a former lagoon which filled in around 300 years ago (figure 10); to the north, along the coast, the Great Dune is a migrating sandy complex over 25m. in elevation which has moved 500m. in 150 years as a result of colonial deforestation; the Atlantic coast of Cape Henlopen is eroding at 3m./yr. (figure 13) and provides approximately 106,000 cubic meters per year of sand to the northward drift; the spit tip is prograding northward into Delaware Bay at rates up to 30m./yr.

FIGURE 12 - Geomorphic elements of the spit system at Cape Henlopen (Kraft et al., 1979).

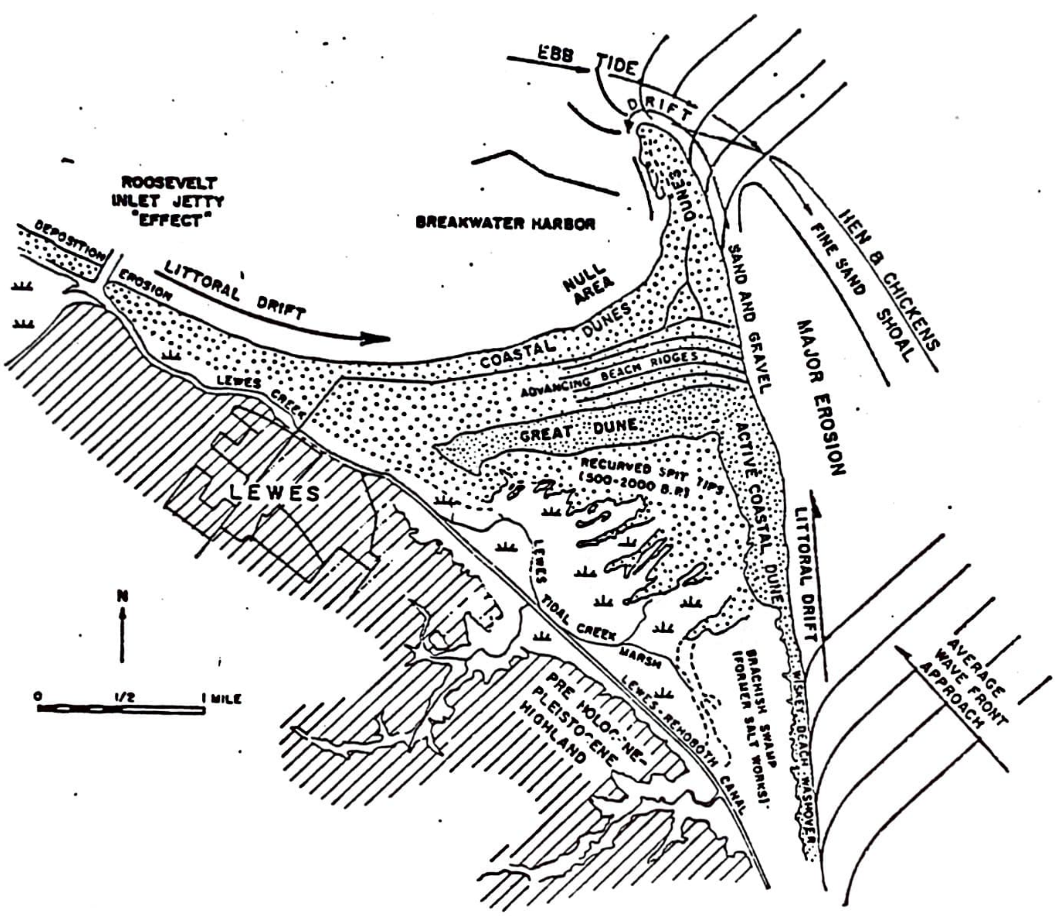
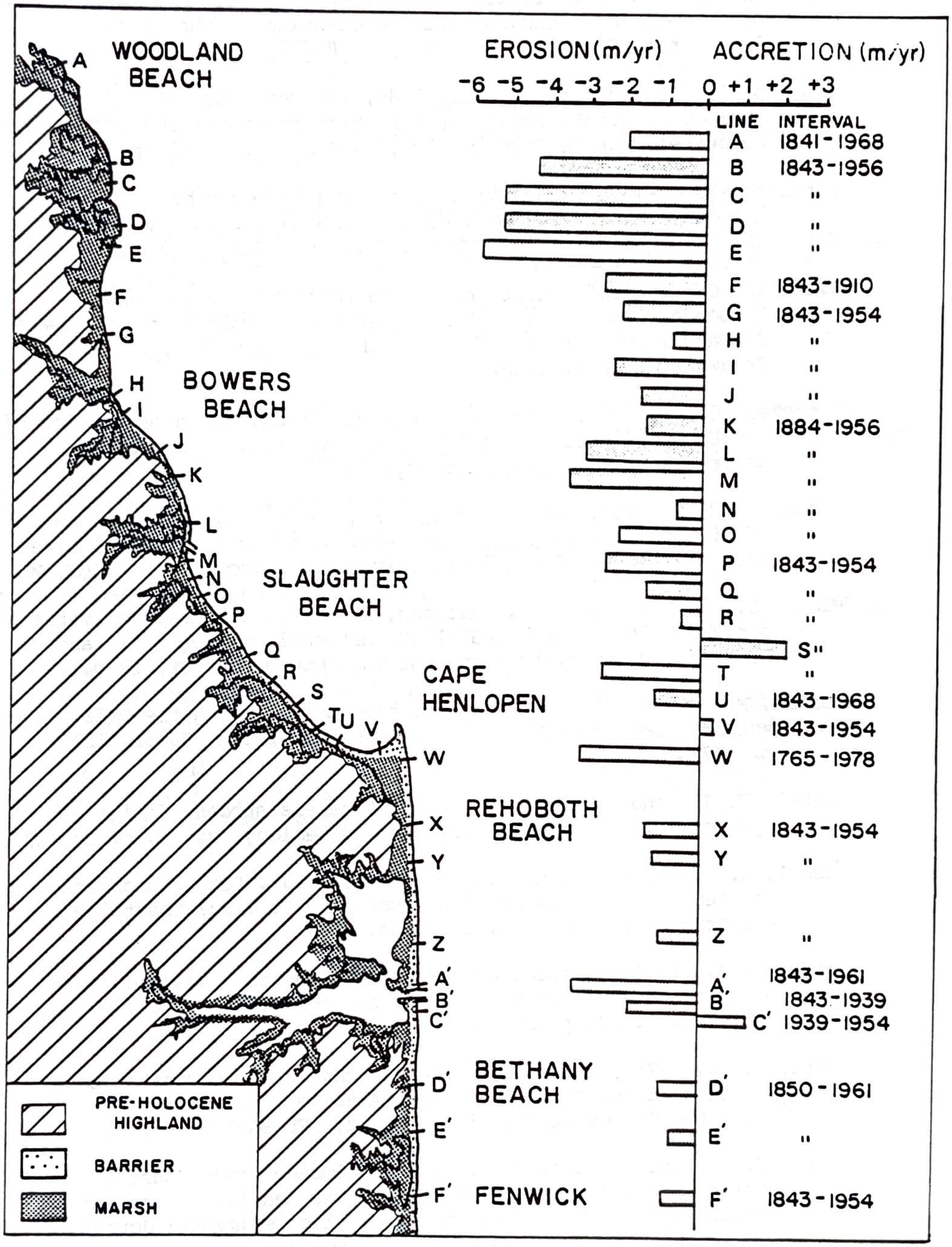


FIGURE 13 - Rates of coastal erosion and accretion (Maurmeyer, 1978).



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PHYSIOGRAPHIC TRIP TO THE GREAT VALLEY OF PENNSYLVANIA

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This trip will show the diversity of the Great Valley in southeastern Pennsylvania, a physiographically distinct feature separating the Valley and Ridge Province to the northwest and the Triassic lowlands to the southeast. In addition, we will visit the southeastern most ridge of the Valley and Ridge Province, Blue Mountain.

As one approaches the Great Valley from the southeast near the town of Reading, the first view of the valley is obtained from atop the highlands known as the Reading Prong. The terrain beyond the broad valley is the Valley and Ridge Province, both are continuous from New York to Tennessee. The valley is underlain by limestones along the southeastern border and towards the center, and by shales and slates to the northwest; both are easily erodible, accounting for the origin of the Great Valley. The ridge to the north is Blue Mountain, the first true ridge of the Ridge and Valley Province, and is composed of sandstones and quartzites which are highly resistant to erosion.

The Ridge and Valley contains Paleozoic rocks, 400 to 600 million years old, whereas the Reading Prong contains Precambrian rocks of 1100 million year age. The Great Valley is actually the southeastern most valley of the Valley and Ridge Province. The rock units which floor the valley extend under the Reading Prong which has been transported northward over the Valley and Ridge strata along a series of thrust faults. The Precambrian gneisses of the Prong are about 2000 feet thick and overlie portions of the same Paleozoic limestones which are exposed in outcrop along the valley bottom (Thompson, 1979).

INTRODUCTION TO THE APPALACHIAN SYSTEM

The Appalachian Mountain System, located along the eastern margin of North America, is a deformed mountain belt perhaps 500 miles wide running from Alabama to Newfoundland. Four to five physiographically and geologically distinct provinces, elongate parallel to the general northeast-southwest axis of the system, comprise the mountain belt and are illustrated in figure 1 from Thompson (1973).

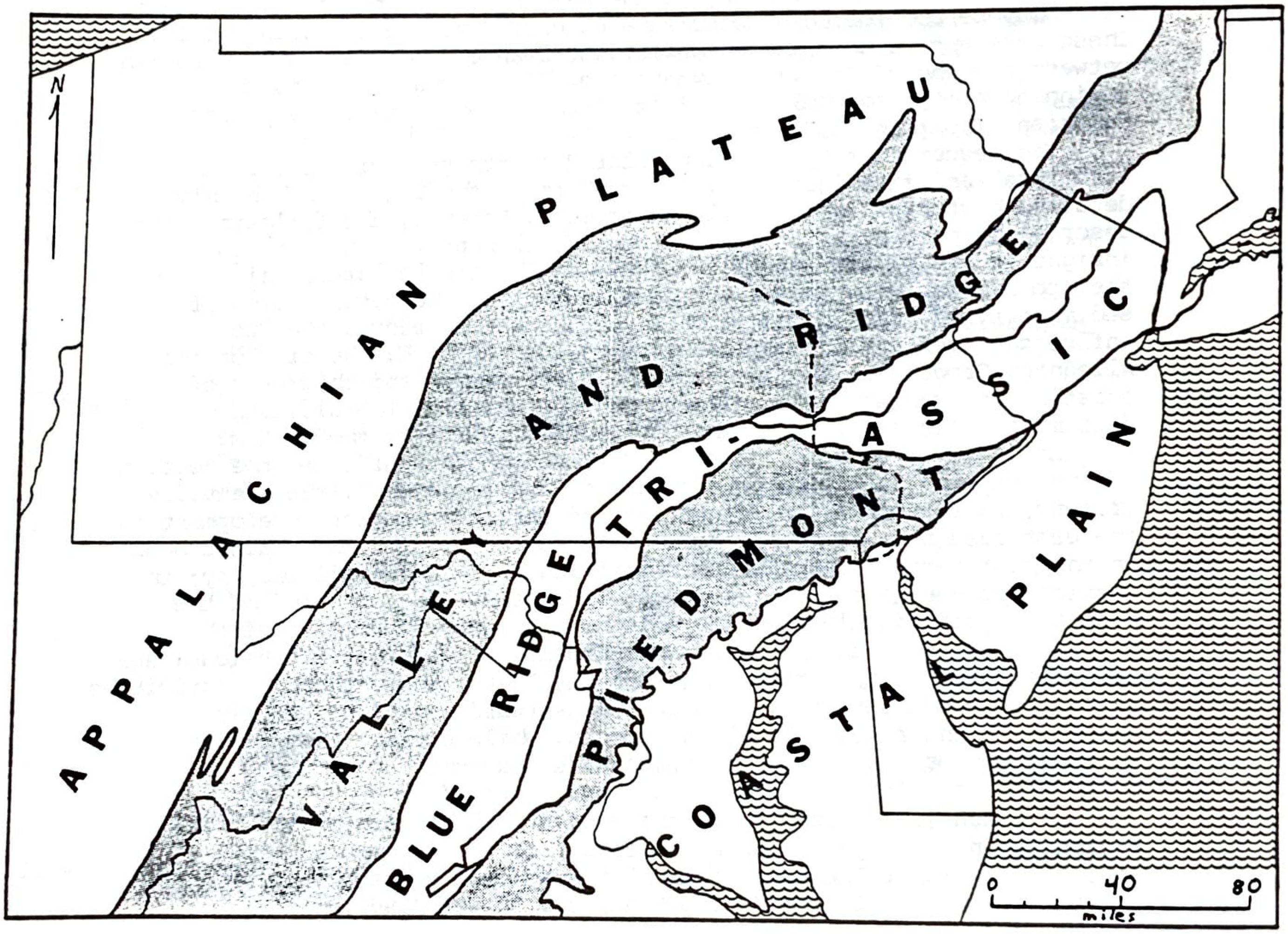


Figure 1. General physiographic provinces of the Appalachians.

The rocks in the Appalachian System are predominantly Paleozoic in age and often exhibit a distinctive style of compressive deformation ranging from simple, upright, open folding to intense, overturned folding, and large-scale thrust faulting. Crustal shortening, as a result, reached 80% to 90% and was accompanied by elevated crustal temperatures in the range of 600 to 700deg.C, often metamorphosing the existing sedimentary rocks of the region.

The sediments comprising the rocks of the mountain belt were originally deposited on the now high-grade metamorphic and igneous Precambrian continental crust. These felsic crystallines were initially sedimentary, but appear to have undergone a mountain-building event similar to later Appalachian events about one billion years ago. This was the Grenville Orogeny of the eastern Canadian Shield, and these rocks may be considered a subsurface extension of the Canadian Shield. These basement rocks must have experienced an enormous amount of erosion between the end of Grenville events one billion years ago and the beginning of the accumulation of Appalachian sediments in the lower Cambrian (Thompson, 1973).

The sequence of Appalachian related events producing the complex structural and stratigraphic relationships of the region is a highly detailed history which is still incomplete. However, the following brief description of the series of contributing elements allows a cursory insight to the history of the mountain chain. The structural history of the Appalachian basin was a strong influence in the distribution of sediment types. Earlier structures were sometimes reactivated to influence later structures (Dennison, 1978). Also, by the time of the Alleghany Orogeny in the Permian, the distribution and thickness of existing sedimentary facies influenced the shape of the ultimate deformation characteristics which would be carried by the system.

At least 10 episodes of structural deformation affected the terrain of the Appalachian region in the last one billion years: the Grenville Orogeny; Late Precambrian fracturing and spreading center development to the east resulting in the ProtoAtlantic Ocean; the Avalonian disturbance on the east margin of the ProtoAtlantic basin; the Taconic Orogeny; the Acadian Orogeny; the Ouachita Orogeny affecting the south end of the mountain system in Alabama; the Alleghany Orogeny; formation of the Triassic Basins in the Palisades disturbance; Cretaceous intrusions; and Cenozoic uplift and intrusions (Dennison, 1978). These tectonic activities repeatedly stimulated the formation of westward spreading clastic wedges from the renewed highland sources, while during times of low sediment production, inbasinal carbonates and other autochthonous materials accumulated.

Dennison (1978) summarizes these events in his history of plate tectonics in the Appalachian basin area from the Precambrian to the Cenozoic, table 1. Portions of Appalachian history are illustrated in the time series of figure 2 from Press and Siever (1978).

TABLE 1.
PLATE TECTONICS IN THE APPALACHIAN BASIN AREA
FROM THE PRECAMBRIAN TO THE CENOZOIC
DENNISON, 1978

Millions of years ago	Event
1,000	Grenville orogeny accreted a new belt of crystalline rocks onto older continental crust of central north America.
820-550	Fracturing of continental crust, development of spreading centers, and expansion of Protoatlantic Ocean.
620-580	Avalonian disturbance (= Ganderian = Virgilinan disturbance) affected east margin of Protoatlantic basin, but did not directly affect Appalachian basin area. The region with the Virgilinan disturbance was welded onto the North American continent east of the Blue Ridge probably in Ordovician time.
600-450	Miogeoclinal trailing edge carbonate bank sloping eastward.
450-425	Taconic orogeny. Beginning of closing of Protoatlantic Ocean in Middle Ordovician initiates true Appalachian basin as a retroarc basin to west of Appalachia quartzose terrain. Taconic orogeny peaked at end of Ordovician. Taconic orogeny seems to be North American extension of Caledonian orogeny.
370-345	Acadian orogeny in northern Appalachians produces Catskill delta complex in Appalachian basin. Orogeny probably resulted from continental collision in northern Appalachians, but there was only minor effect in southern Appalachians.
300	Ouachita orogeny caused by mid-Pennsylvanian closing of southern oceanic basin. Orogeny affected Alabama outcrops of southern Appalachians and Alabama beneath Coastal Plain.
265	Alleghany orogeny deforms eastern margin and central portion of Appalachian basin. Formed by continental collision which destroyed Protoatlantic Ocean and assembled Gondwana continent.
190	Triassic basins form in incipient stages of opening of present Atlantic Ocean. Igneous intrusion and extrusion. (Palisades disturbance).
185-140	Peridotites intruded along keel-line of Appalachian basin as a result of rebound adjustments after subsidence ceased.
150	Alkalic igneous intrusions in western Virginia on trailing edge of North American plate, along reactivated fracture zone, perhaps crossing a mantle plume.
50-45	Cenozoic uplifts and igneous intrusion in Virginia and West Virginia, just west of Jurassic intrusions. The 38th Parallel fracture zone is once again reactivated by differential movement along trailing edge.
Now	Slight compressive stress on trailing edge of North American plate, as mantle slips slightly beneath the plate.

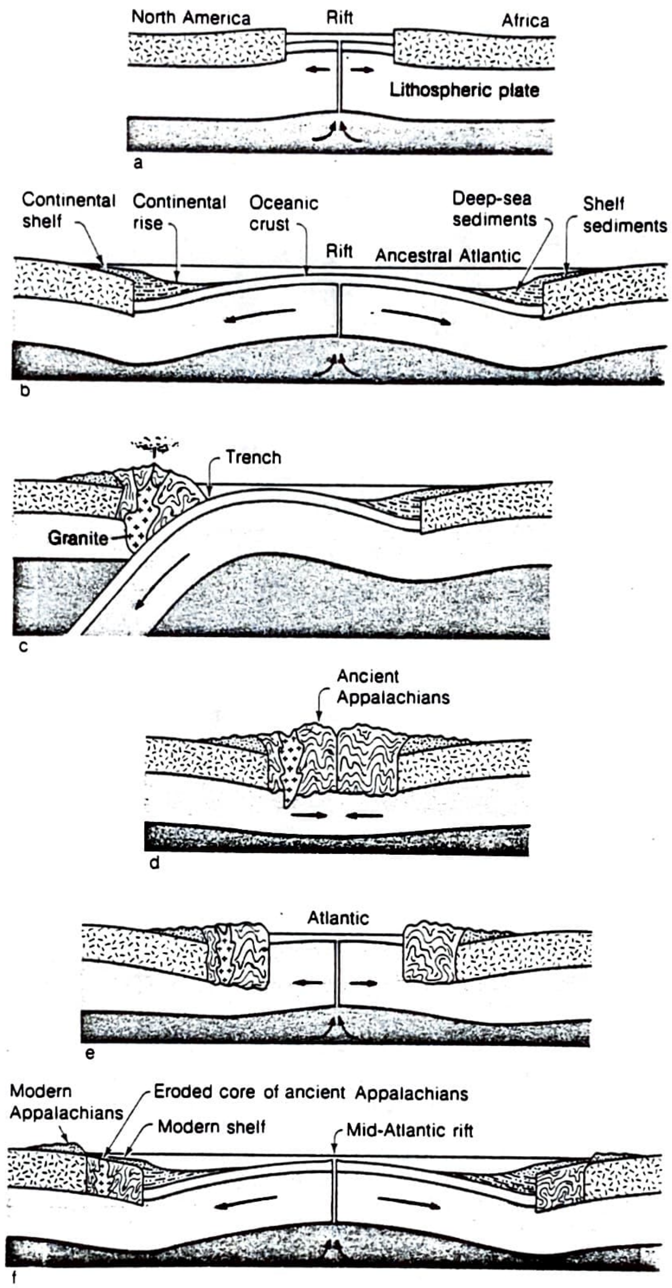


Figure 2. Stages in the formation of the Appalachian Mountains. North America and Africa split apart more than 600 million years ago, an ancestral Atlantic opened and sediments were deposited on the margins of the receeding continents (a and b). About 450 million years ago, the Atlantic began to close, subduction was initiated, and the geosynclinal deposits were deformed, intruded and uplifted (c). About 370 million years ago, the Atlantic closed as North America collided with Africa and Europe (d). the modern Atlantic opened about 200 million years ago with the fissuring of Pangaea, and marginal sedimentation began to develop anew (e and f).

THE GREAT VALLEY

The Great Valley varies from 13 to 29km wide in southeastern Pennsylvania and is composed of several geographically determined subdivisions: the Cumberland Valley, the Lebanon Valley, and the Lehigh Valley (figure 3; Stephens et al., 1982). Rain fall averages just over 100cm/yr producing the familiar humid landforms associated with the central Appalachians.

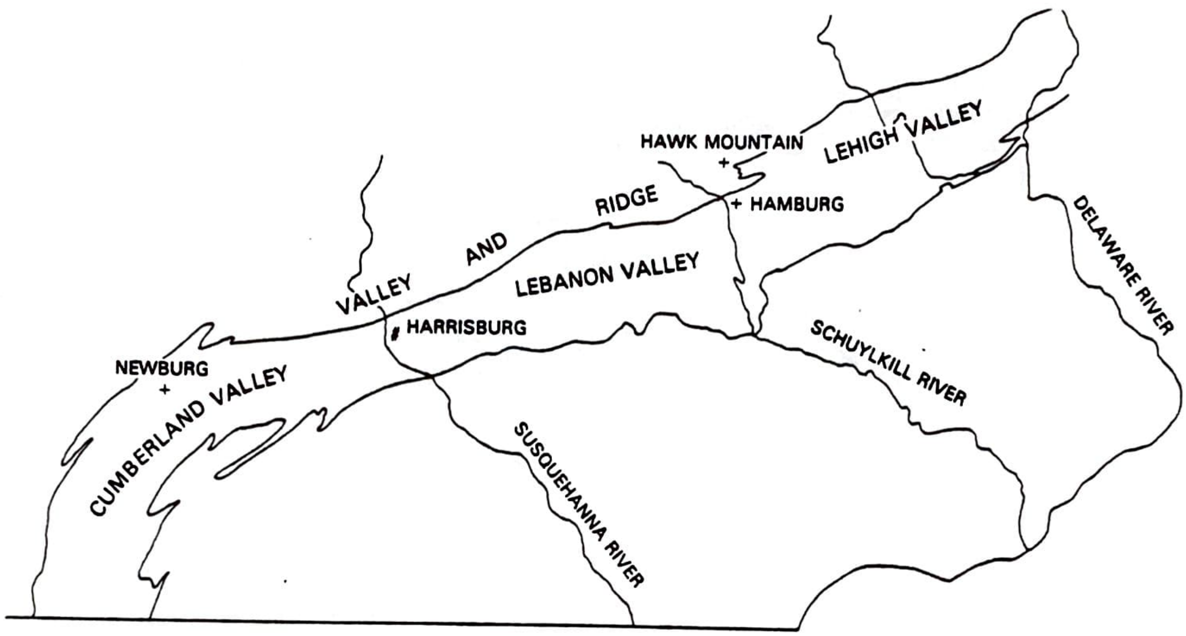


Figure 3. Longitudinal subdivisions of the Great Valley in Pennsylvania (Stephens et al., 1982).

Formerly heavily forested, the area was cleared by settlers in the 18th and 19th centuries. During the last sixty years, the Great Valley has slowly undergone a transition from mainly agricultural usage to a mixed agricultural and urban/industrial development (Stephens et al., 1982). This has resulted in small, local population centers formed from remnant rural agrarian communities, and larger urbanized areas such as Allentown, Reading, Harrisburg, and Bethlehem. Because these larger towns originally grew on the most fertile carbonate-rich portions of the region, they are now expanding over the most suitable farmland, leaving the shaley and sandy Martinsburg Formation to support the agriculture of the valley (Stephens et al., 1982). Additionally, as the population stress increases in the southeastern portion of the valley, environmental problems begin to surface with increasing frequency, including: sinkholes, ground subsidence, and a decreasing and often polluted water supply, all related to the underlying carbonates.

A drive across the Great Valley reveals three topographic levels which were considered by William Morris Davis, in his peneplanation theory, as residual erosion surfaces of specific ages. The highest level, at about 350m, may be viewed to the north atop Blue Mountain. This surface is at the eroding edge of the Silurian Tuscarora quartzite in the west and the Shawangunk conglomerate in the east, and is named the

Schooley Peneplain. The lowest landscape averages 100m elevation south of Harrisburg but rises to 150m in the Lebanon Valley with a local relief of about 30m. This is the Somerville surface and is underlain by the Cambrian and Ordovician limestones and dolomites found on the valley floor. Further to the north the Great Valley is underlain by eroded clastics upon which has been projected the Harrisburg erosion surface, the third and intermediate peneplane (Stephens et al., 1982).

Successive peneplanation was originally advanced about a half century ago to explain the remarkably uniform and flat summits of the more pronounced ridges of the Valley and Ridge Province and the common elevations of the intervening valley floors (Thompson, 1979). Thompson, 1979, states that the most widely accepted version of peneplanation is that of Johnson, 1931 (figure 4). Although highly debated over the years (Hack, 1960; Meisler, 1962; Pierce, 1965; Epstein, 1965) the concept of peneplanation has recieved recent support (Sevon, 1981; Berry, 1982).

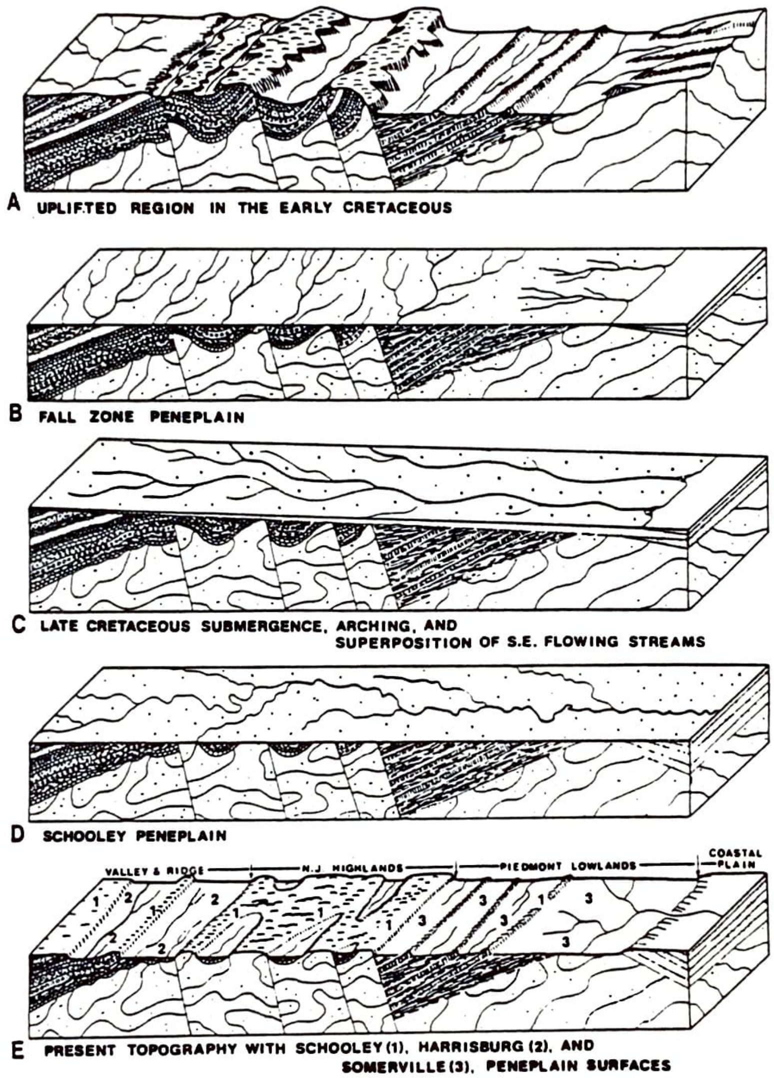


Figure 4. Stages in the successive peneplanation and uplift of the central Appalachian region, as concieved by Johnson, from Wolfe (1977).

THE VALLEY AND RIDGE

The Valley and Ridge Province contains sedimentary rocks of Cambrian through Pennsylvanian age which have been folded into large upright anticlines and synclines. The nearly horizontal axes of these structures often extend for distances up to 200 miles without interruption. Erosion of these long folds has produced a series of distinct ridges supported by resistant sandstones, and adjacent valleys floored by weakly resistant shale. The linear topography composed of parallel sets of these features has lead to the name Valley and Ridge for this province.

The Cambrian and most of the Ordovician rocks are shallow water algal limestones and dolomites, these include: the Upper Cambrian Conochocheague Group of grey to tan limestones and dolomites formed in a shallow water, carbonate bank environment, the lower parts contain limestone boulder conglomerates interpreted to be ancient continental slope deposits; the Lower Ordovician Beekmantown Group of fossiliferous limestones and dolomites deposited within the tidal range during four major cycles of sea-level fluctuation, overall thickness is 3500 feet; the Middle Ordovician limestones and dolomites of the Trenton Group which are richly fossiliferous with brachiopods, pelecypods, corals, and algal stromatolites; and the Upper Ordovician Martinsburg Shale which contains interbedded, carbonaceous grey shale and sandstone with evidence of deeper water deposition as turbidity currents and distal shelf facies.

Above the lower section of carbonates, the Valley and Ridge Province contains Mid-Ordovician to Devonian graywackes and arkoses, including: the Lower Silurian Tuscarora Formation of grey to white quartz sandstones and conglomerates with the lowest conglomeratic horizon known as the Shawangunk formation, these facies are interpreted as braided stream fluvial deposits and are the major ridge formers of the Province; the Middle Silurian Clinton Group of interbedded shales, sandstones and limestones of continental and marine origin, interpreted to be a shoreline complex of barrier-island sands, lagoonal muds and offshore limestones; the Upper Silurian Bloomsburg Formation of red sandstones and shales which are strongly cross-bedded and channeled suggesting a fluvial and floodplain origin, these grade westward into marine shales; the Lower Devonian Helderburg Group and Oriskany Sandstone, both of which are shallow marine facies with the Helderburg of carbonate composition and the Oriskany a quartz sandstone.

Above the Lower Devonian, a series of interbedded sandstones and shales are found indicating increasingly shallow water deposition. These compose the Middle Devonian Hamilton Group and Portage Group which were deposited in deep marine and continental rise depths, respectively, and the Upper Devonian Chemung and Catskill Groups, which were of shallow marine and fluvial origin, respectively. By the Late Paleozoic a series of well developed fluvial deposits are preserved, some of which may possibly contain some cyclothem deposition.

In all, the Valley and Ridge section reaches nearly 35,000 feet in thickness, with the lower 15,000 composed of Cambro-Ordovician carbonates which are generally exposed along the southeast boundary of the Province adjacent to the Triassic lowlands. The Paleozoic section comprising the Valley and Ridge Province has been summarized by Thompson (1973) and is provided in table 2. Additionally, the generalized physiography of the entire central Appalachian region is shown in figure 5.

TABLE 2.

THE PALEOZOIC STRATIGRAPHIC SECTION IN SOUTHEASTERN PENNSYLVANIA

THOMPSON, 1973

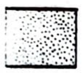
UNCONFORMITY

PENNSYLVANIAN

LLEWELLYN FORMATION: gray sandstones, shales, coals and minor limestones, interbedded in one- to 300-foot-thick beds. Coal beds recur in sequences of repeating strata, but perfection of sequences and details of repitition are not great enough to warrant the name cyclothem. These beds are landward extensions of Pennsylvanian cyclothems of Mid-Continent region. Fossiliferous, with excellently preserved terrestrial plant fossils. Thickness 3500 feet. Middle and Upper Pennsylvanian; correlative with time-equivalent coal-bearing strata of western Pennsylvania. Exposed at Stops 10 and 11.

POTTSVILLE CONGLOMERATE: light gray to white quartz sandstone and conglomerate. Unusually pure and highly siliceous; silica cement makes the Pottsville a major ridge-former in Valley and Ridge. Conglomerate contains exclusively quartz pebbles. Fluvial deposits, probably in braided streams. Thickness 1400 feet. Basal Pennsylvanian.

MISSISSIPPIAN



MAUCH CHUNK FORMATION: predominantly red sandstone and shale. Fluvial deposits; fining-upward cycles of meandering streams common. Contains rare vertebrate remains. Becomes finer-grained to northwest. Thickness 2500 feet. Upper Mississippian.

POCONO FORMATION: white to light gray quartz sandstone and conglomerate, with minor interbedded shale. Extremely resistant to weathering, primarily because of silica cement and highly quartzose character. A major ridge-former in Valley and Ridge. Probably fluvial deposits; unfossiliferous, well-sorted sands, highly cross-bedded. Grades up from underlying Catskill redbeds. Thickness 1500 feet. Exposed at Stop 9. Basal Mississippian.

DEVONIAN

CATSKILL GROUP: red to brownish-red shales and sandstones. Includes many separate formations, all generally similar. Type examples of fluvial, floodplain deposition; contains original fining-upward cycles. Base becomes younger to west. Initiated Acadian molasse deposition. Thickness at least 5000 feet in Pennsylvania; thinner elsewhere. Upper Devonian.

CHEMUNG GROUP: gray to greenish-gray sandstones and shales. Fossiliferous, mainly with shallow-water forms. Inferred to be of nearshore, shallow-marine origin. Thickness 1000-1500 feet. Middle to Upper Devonian.

PORTAGE GROUP: gray to brown, interbedded sandstones and shales. Graded bedding and basal scour features common. Flysch; turbidite deposition in "deep" marine basin. Includes several massive sandstone units. Thickness 2000-2500 feet. Middle Devonian.

HAMILTON GROUP: gray to black shales with minor interbedded sandstones and limestones. Fossiliferous, in many cases abundantly so. Interpreted to be offshore-marine, possibly deep-water origin. Includes MAHANTANGO FORMATION of Stop 8, and ONONDAGA Limestone at base. Exposed at Stop 8. Thickness 2000 feet. Middle Devonian.

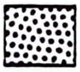
ORISKANY SANDSTONE: white to buff, nearly pure quartz sandstone. Fossiliferous with shallow marine brachiopods. Used extensively for glass sand. Nearshore, shallow marine deposits; in Mid-Continent Oriskany is basal sandstone of Kaskaskia cratonic sequence of Sloss (1963). Thickness 100 feet. Lower-Middle Devonian.

DEVONIAN

HELDERBERG GROUP: gray limestones, dolomites and shales. Abundantly fossiliferous. Deposited in carbonate shoreline complex, including tidal flats, channels, shallow sea floors and bays, of a transgressing inland sea. Represent the carbonate bank stage of Acadia geosynclinal cycle. Thickness 350 feet. Lower Devonian.

TABLE 2. (cont.)

SILURIAN



UPPER SILURIAN CARBONATES: gray to buff limestones, dolomites and shales, much resembling the overlying Helderberg group. Includes KEYSER, TONOLOWAY LIMESTONES (fossiliferous dolomitic, nearshore marine) and WILLS CREEK SHALE (fossiliferous, nearshore marine with clastic influx). Basal carbonate units of Acadian geosynclinal cycle; represent carbonate bank and platform deposition. Thickness 1000 feet. Upper Silurian.

BLOOMSBURG FORMATION: Red sandstone and shale, with minor conglomerate. Strongly cross-bedded and channeled. Unfossiliferous. Fluvial, floodplain deposits; fining upward cycles common. Taconic molasse. Grades westward into marine shales. Exposed at Stop 7. Thickness 2000 feet. Upper Silurian.

CLINTON GROUP: Interbedded sandstones, shales and limestones. Beds range from 0.1 to 30 inches thick. Fossiliferous in restricted horizons. Includes ROSE HILL SHALE, KEEFER SANDSTONE and ROCHESTER SHALE in ascending order. Iron ores, typical of Clinton elsewhere are not present in eastern Pennsylvania. Continental and Marine origin; a shoreline complex with barrier-island sands, lagoonal muds and offshore limestones. Thickness 500 feet. Middle Silurian.

TUSCARORA FORMATION: gray to white quartz sandstone and conglomerate. Conglomeratic horizon called SHAWANGUNK CONGLOMERATE. Nearly pure quartz rock; pebbles in conglomerates are quartz and chert. Resistant; a major ridge-former in Valley and Ridge. Becomes less conglomeratic and finer-grained from east to west. Unfossiliferous, fluvial deposits, probably in braided streams. Initiated Taconic molasse deposition in eastern Pennsylvania. Exposed at Stop 7. Thickness 500-1000 feet. Lower Silurian.

UNCONFORMITY

ORDOVICIAN

MARTINSBURG SHALE: interbedded gray shale and sandstone. Sandstone beds show grading, sole marks, scour fills and channels, and contain fossil debris of shallow-water animals, chiefly brachiopods and crinoids. Pelagic shale is most common rock type; lower half to third of Martinsburg is this shale. Turbidite graywacke sandstones and typical flysch constitute remaining half to two thirds. Turbidite, flysch deposition in "deep" marine basin. Top 100 feet are shallow-water siltstones transitional to molasse; however, this has been eroded away at most localities east of Susquehanna River. Degree of erosion of upper beds increases to east, 1000-2000 feet. Exposed at Stop 7. Preserved thickness at least 12,000 feet, even after erosion. Middle and Upper Ordovician.

TRENTON GROUP: gray to buff limestones and dolomites. Richly fossiliferous with brachiopods, pelecypods, corals and algal stromatolites. Includes many, thin formations; major unit is JACKSONBURG LIMESTONE. Shallow marine deposits, carbonate-bank environment. Much tidal-range carbonate present. Last carbonate deposits of Taconic geosynclinal cycle. Thickness 600 feet. Middle Ordovician.

BEEKMANTOWN GROUP: gray to tan limestones and dolomites. Fossiliferous in certain regions, unfossiliferous in others. Alternating limestone and dolomite in four major cycles, each of which constitutes one formation. Shallow marine origin, on carbonate bank which for long periods of time was within the tidal range to produce supratidal carbonate rocks. Thickness 3500 feet. Lower Ordovician.

CAMBRIAN

CONOCHOCHEAGUE GROUP: gray to tan limestones and dolomites, with sandy zones in the lower parts. Shallow-marine deposits, near to tidal zone on carbonate bank. In southeastern Pennsylvania, lower parts contain limestone boulder conglomerates, interpreted to be ancient continental slope deposits transitional to eugeosyncline. Thickness 2000 feet. Exposed at Stop 6. Upper Cambrian.

ELBROOK FORMATION: gray to black, dense, cherty limestones and dolomites. Includes several sub-formations, notably the CONESTOGA LIMESTONE at the base, seen at Stop 1. Sparsely fossiliferous with marine animals and calcareous algae. Shallow-water, nearshore-marine carbonate-bank deposits. Continuous throughout Central and Southern Appalachians, Thickness 3000 feet. Middle Cambrian.

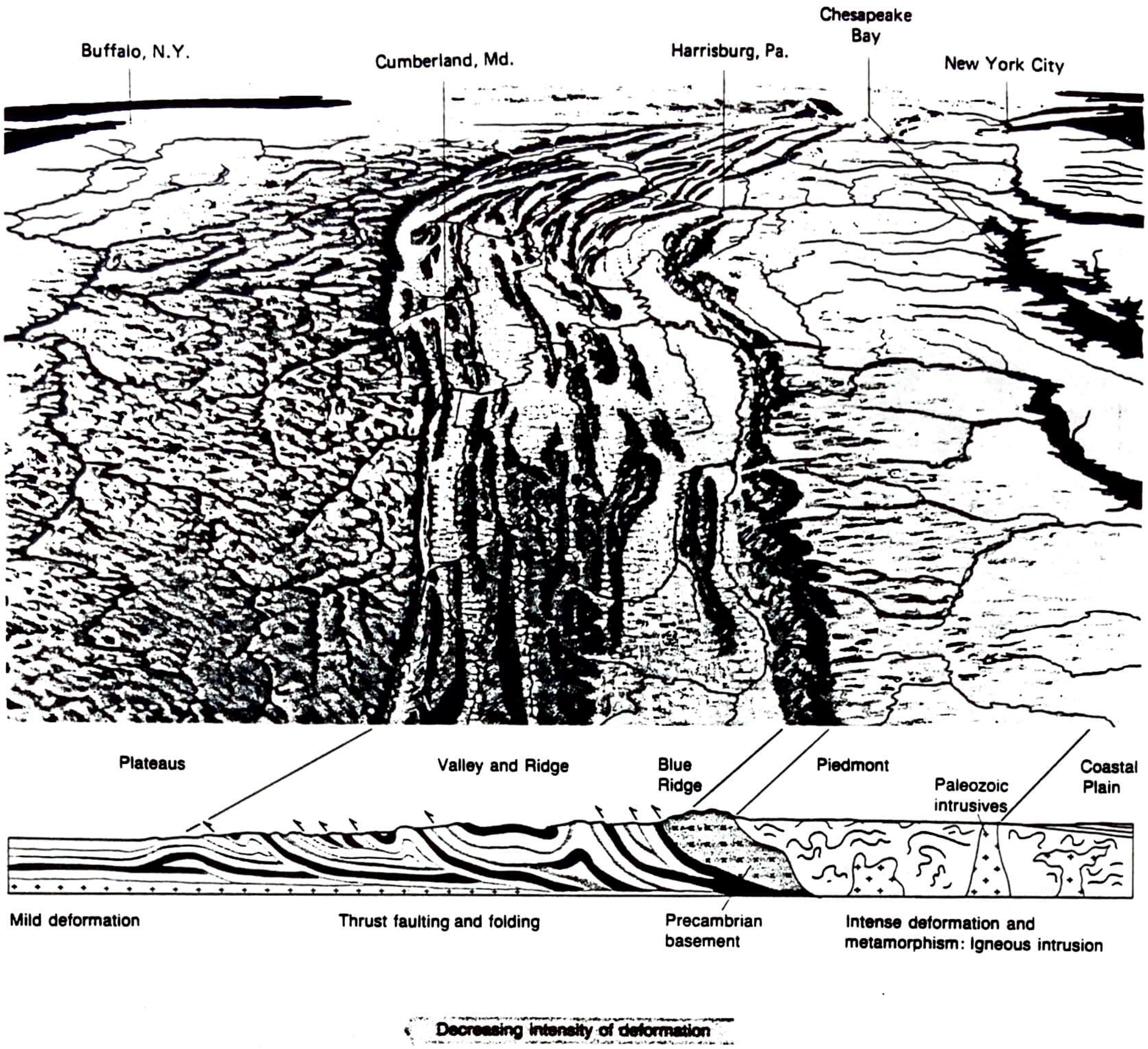


Figure 5. Aerial view looking northeast and idealized cross-section of the Appalachian region (Stanley, 1986).

THE GREAT VALLEY TRANSECT FROM READING TO HAWK MOUNTAIN

STOP 1 - THE PAGODA

It may seem strange to start a geology trip at a Chinese pagoda in a Pennsylvania Deutch city, but this site offers an overview of the whole valley. You are standing on Mount Penn, the local name for the Reading Prong, a collection of Precambrian rocks that form the southeast rim of the Great Valley. Here the Schuykill River cuts a gap through the highlands, forming a transportation route that has resulted in the growth of the city of Reading. Twenty miles in the distance one may see the water gap in Blue Mountain where the Schuykill flows onto the gently rolling surface of Great Valley. Along with the general overview, other items to be discussed at this stop include the local economic geology, the radon problem, and the influence of the landforms on human occupation.

STOP 2 - LIMESTONE OUTCROP

In Reading Park to the east of the U.S. 222 bridge over Tulpehocken Creek, there is an old quarry adjacent to the abandoned Union Canal. The structure and lithology of the valley carbonates are to be discussed at this point. The steeply dipping Maiden Creek Member of the Cambrian Allentown Formation (part of the Conococheague Group) displays lithologic characteristics ranging from oolitic limestone to siltstone-shale facies. Numerous joints show why this limestone is such a good aquifer and also the site of numerous karst collapses in the Reading and Allentown areas.

STOP 3 - SUFFOSION SINK

On the berm of the U.S. 222 bypass of Kutztown there is a recent example of a suffosion sink. The processes and consequences of karst collapse will be discussed at this stop. In addition, a discussion of the Jacksonburg Formation (of the Ordovician Trenton Group) carbonates, and comments on the fertile agricultural land nearby will occur.

STOP 4 - SCHOFFERS CAVE

West of Kutztown on the way to the cave there is a drastic landscape change. The flat valley agricultural landscape is replaced by hilly forested slopes of the shales of the Middle and Upper Ordovician Martinsburg Formation. The large hill in which the cave is located marks the beginning of the Upper Cambrian Onyx Cave limestone which has been thrust over the surrounding shales. The cave entrance shows an anticlinal structure with a well defined fault. The rocks in this location are part of the Hamburg Klippe sequence, a highly debated unit which may have been transported from the Taconic sequence of New York and New England.

THE HAWK MOUNTAIN AREA

Hawk Mountain is a local peak of Blue Mountain, the eastern most ridge of the Valley and Ridge Province. The crest is composed of the coarse clastics of the Lower Silurian Tuscarora Formation and the Middle Silurian Clinton Group. The ridges in this area bear thin, stoney soils which are poor for farming in contrast to the well developed regolith of the valley floor. The dividing line between these regions is apparent on the landscape, the sandstone soils are covered with forest, while shale and carbonate soils are farmed.

Although this portion of the region was not actively glaciated during the Pleistocene advances, the Wisconsinan ice front was just to the north of Blue Mountain in Northhampton County, and the ice pushed through the Delaware Water Gap and into the valley for a short distance. Terminal moraines indicate that Hawk Mountain was about 35 miles south of the ice sheet. The Great Valley and the ridge crests were subject to a periglacial climate during the Wisconsinan maximum and evidences of frozen, frost-shattered bedrock abound (Potter and Moss, 1968).

Two local features, the River of Rocks and the Blue Rocks Boulder Field, were created 11-12 thousand years ago during the advent of these conditions. Large joints in the ridge-forming quartz conglomerates were subjected to ice-related mechanical weathering and an accumulation of boulder and cobble-sized clasts developed at the two sites (figure 6). Eventually, through solifluction, the blocks moved downhill forming these boulder fields which rest on the Martinsburg shales. It is conjectured that the development of a winter ice core in the deposit would have provided the water necessary to initiate movement upon the sloping surface of the underlying permafrost during summer melts.

Movement ceased about 10 thousand years ago, verified through the techniques of lichenometry. Today, a stream still flows below the rocks carrying away the fines. Slowly, but relentlessly, vegetation is covering the edges of these boulder fields. Where stream action can not carry away the fine material, a veneer of soil fills the interstices and covers the rocks giving the shrubs and trees their needed foothold.

PENNSYLVANIAN
Pop-Post-Pottsville Formations; sandstones and shales with conglomerates and mineable coals
Pp-Pottsville Group; sandstones and conglomerates with thin shales and coals

MISSISSIPPIAN
Mmc-Mauch Chunk Formation; shales with sandstones
Mp-Pocono Group; crossbedded conglomerates and sandstones with some shales

DEVONIAN
Dck-Catskill Formation; shale and sandstone
Dho-mixed sedimentaries
Dm-Marine beds; shales and sandstones
Doh-mixed sedimentaries

SILURIAN
Sbm-McKenzie Formation; shale with limestone interbeds
Ss-Shawangunk Formation
-Tuscarora Formation

ORDOVICIAN
Ob-Beekmantown Group; dolomite
Ohm-Hershey and Myerstown Formations; limestone
Om-Martinsburg Formation; shale with sandstone
Oms-Martinsburg Formations

NL-North Lookout
SL-South Lookout

Figure 6. Generalized geology and geography of the Hawk Mountain area.

STOP 5 - HAWK MOUNTAIN TRAILS

As we leave the Visitor's Center (figure 7) note the boulders of Tuscarora/Shawngunk conglomerate, interpreted as fluvial in origin. Also, note the slickenside development along the axial plane of the inactive fault in the road-cut.

At South Lookout a fine view of the River of Rocks and the erosional valley beyond is available. Notice that the quartz conglomerates on which you stand are the continuation of a layer that can be seen across the valley. Also take note of the differential soil and landscape development resulting from the variation in lithology. The trail follows the crest of Blue Mountain from New Jersey south into Virginia through the typical eastern deciduous hardwoods and evergreens with rhododendron and mountain laurel groundcover.

At Old Lookout the trail splits, with the Ridge Trail following the more strenuous route. Further, after the wooden bridge, exposures of the ridge clastics contain some veining resulting from either metamorphic or authigenic processes. Note the well developed quartz crystals on the exposure immediately before the River of Rocks trail sign.

At the Express Route sign, the trail begins the final climb to North Lookout. We will return by the Scenic Route. The same conglomerates as found by the Visitor Center line both sides of the trail. These extend all the way to North Lookout. As you reach the crest notice the abrupt and complete change in vegetation, the hardwoods and mountain laurel understory are replaced by hemlocks and rhododendrons.

To the north of North Lookout are the readily farmed red soils of an ancient flood plain, these contrast with the forested soils of the sandstone and shale strata. You are standing on the source of the River of Rocks which may be seen extending down the hillside from this point. It is interesting to consider the relationships of time, watershed size, and discharge required to enact the processes responsible for this feature.

The stairs lead to the Hall of the Mountain King, a huge cleft in an exposure of the Tuscarora Formation. The cleft was created by the mining of sand for glass production and building construction. The trail you are following was cut to carry the sand on carts to a gravity railroad where the material was lowered to the valley floor. Little of the railroad remains except the foundation which housed a cable and brake. The rocks here are not highly metamorphosed, as a result, some primary sedimentary structures are still visible. Notice the dip of the bedding planes on both sides of the cleft. These crossbeds were formed on the sloping surface of a sandbar.

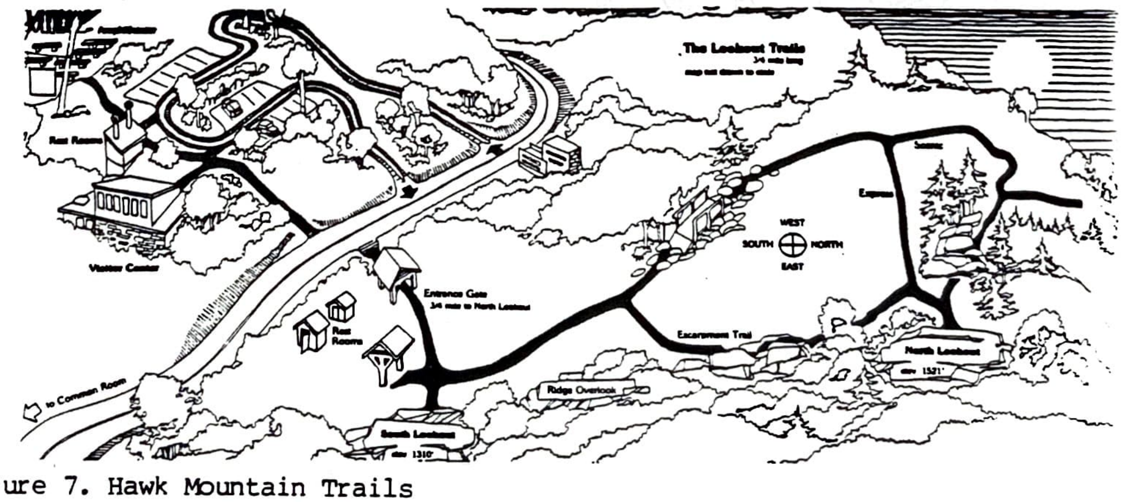


Figure 7. Hawk Mountain Trails

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MINERAL COLLECTING IN CHESTER COUNTY, PENNSYLVANIA

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The metamorphic, igneous, and sedimentary rocks in Chester County have allowed a long history of economic geology. Today the exploited sites, as well as the economically insignificant ones, provide numerous localities for mineral collecting. This trip provides participants the opportunity to sample the diverse nature of mineral occurrence here. The first stop, Steidler's Quarry, is a privately-owned, simple pegmatite yielding beryl and mica in a quartz matrix. Stop 2, French Creek Mine, provides magnetite and chalcopyrite resulting from a diabase intrusion. The third stop visits the Benjamin Franklin Graphite Mine, which produced graphite from Precambrian gneisses in the Honeybrook Upland. The processing plant still stands next to the open cut where graphite flakes can be collected. Stop 4, the Brookdale Mine, is noted for the occurrence of pyromorphite. Authigenic quartz crystals are the target at the last stop.

INTRODUCTION

Chester County is one of those places where a collector is able to find minerals within a reasonably small area that are related to all three rock types. This trip visits localities in the northern part of the county to collect igneous mica and beryl from a pegmatite, contact metamorphic magnetite ore adjacent to an igneous intrusion, metamorphic graphite from a schist, hydrothermal lead-zinc ore, and authigenic quartz from a sandstone.

In very general terms, the geology of Chester County can be described by dividing it into three regions: north of the Chester Valley, the Chester Valley and south of the Chester Valley (see Field Trip A for a more detailed discussion of Chester County geology). The Chester Valley (figure 1) is a structurally complex, linear feature trending NE-SW through the center of the Chester County. The north ridge of the Chester Valley is underlain by resistant quartzite of the Chickies Formation. The southern border is marked by the Martic Line; the floor of the valley is composed of Cambrian to Ordovician limestones and dolomites. The region south of the Chester Valley has traditionally been called the Glenarm terrane. Here, the Precambrian Baltimore gneiss is unconformably overlain by metasediments of the Glenarm Group (Setters Formation and Cockeysville marble) along with the Wissahickon and Peters Creek schists, and the Octoraro phyllite. Small serpentinite bodies are relatively common. Precambrian granulite and amphibolite grade gneisses and an anorthosite intrusion occur north of the Chester Valley in the Honey Brook Upland. In the extreme northeast, these gneisses are partially overlain by Triassic sedimentary rocks. Intrusive igneous bodies, such as pegmatites and Triassic diabase, are scattered generously throughout the county. Together, the rocks in Chester County comprise a complex of folded and faulted metamorphic, igneous, and sedimentary rocks which record a long tectonic history.

As a result of this geology, Chester County has a long and diverse history of economic ore production. As early as 1680, Charles Pickering prospected for gold and silver in the Phoenixville area (Evans, 1984). Later around 1717, iron ore associated with the diabase dikes in the northern part of the county supplied George Washington's Continental Army and gave rise to the steel industry in Coatesville and Phoenixville. From 1810 until World War II, the serpentine bodies of southern Chester County supported a large chrome and talc industry. In the latter half of the 1800's, lead, zinc, and copper were produced from the mining district around Phoenixville. More recently, feldspar was quarried from pegmatites for postwar construction and corundum from a serpentine body was mined for use as abrasives.

As of 1975, 284 of the 2300 known mineral species had been found in Pennsylvania (Geyer, Smith, and Barnes, 1976), with most coming from the southeastern part of the state. It is surprising that despite urbanization, two or three new species are added to the list each year. Unfortunately, mineral localities are being sold to land developers at an alarming rate. However, the excavation of these sites is providing, although for a short time, some excellent collecting. Most of the specimens found today are not of the same caliber as those recovered in the

past. For example, in 1851 Charles M. Wheatley sent an exhibit to the Mineralogical Department of the New York Crystal Palace Exhibition. In a review of the collection, Professor B. Silliman, Jr. wrote, "We speak understandingly and without exaggeration, when we say that the sulphate and molybdochromates of lead in Mr. Wheatley's collection are the most

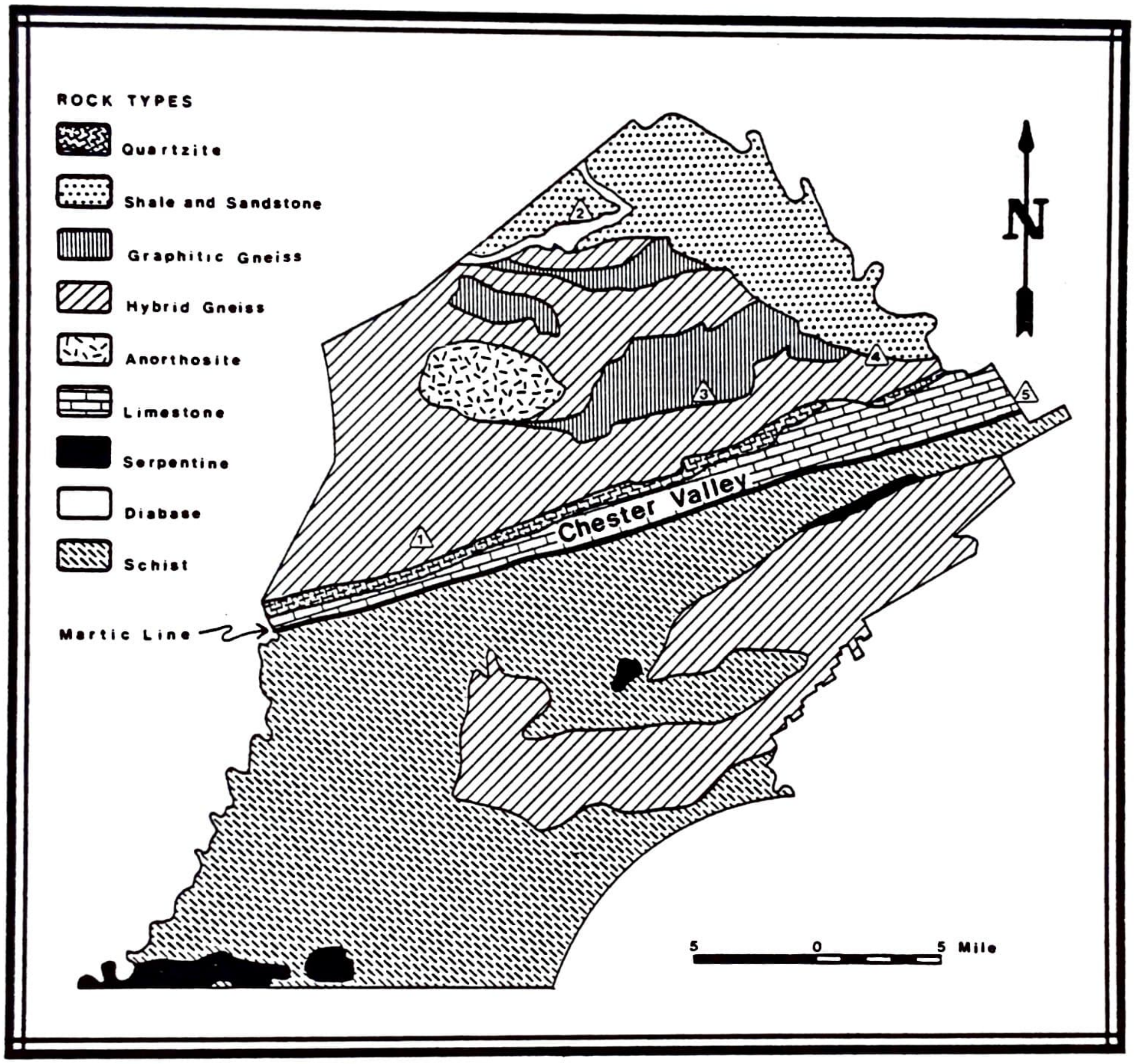

Figure 1. Generalized geologic map of Chester County, Pennsylvania. (Modified from The Chester County Planning Commission, 1973).

magnificent metallic salts ever obtained in lead mining, and unequaled by anything we have seen in the cabinets of Europe." (Evans, 1984). Nonetheless, the dumps of these old localities are still yielding specimens of astounding quality and attracting mineral clubs from as far away as Canada.

At this time I would like to add a personal note on safety and proper clothing. In Chester County it is essential that gloves and proper clothing be worn, not only to protect the collector from flying rock particles, but also from poison ivy and thickets which abound in the county. Unfortunately, at times these abandoned sites become convenient legal as well as illegal dumping grounds. Hard toe shoes are therefore not only for support on rugged terrain but to protect from nails and glass. Finally, when out collecting be sure to ask permission from the land owner. As was pointed out by Martin Rutstein in last years guide book, too many localities are closing and more care should be taken to help keep open those that remain.

FIELD TRIP ROAD LOG

MILEAGE		DIRECTIONS
CUMULATIVE	RUNNING	
0.00		From Church Street in front of Schmucker Science Center, turn right on Rosedale Avenue.
	0.25	Stop sign. Turn right on South New Street.
	0.35	Light. Turn left on Price Street. Proceed one block.
	0.10	Turn right on South Wayne Street.
	0.50	Light. Turn left on Hannum Avenue (This becomes US Route 322W).
	4.80	Octoraro phyllite outcrop on left side of road.
	1.20	Railroad tressel and grated bridge over the Brandywine River.
	0.90	Light. Turn left on East Lancaster Avenue. Follow the signs for US Route 322W.
	0.10	Light. Turn right on Manor Avenue (continue on US Route 322W).
	1.20	US Route 30 Bypass. Turn right on the entrance ramp for US Route 30W Bypass.
	5.70	Exit for PA Route 82. Exit and turn right on PA Route 82S.
	0.80	Turn right on Manor Road, directly across from a pegmatite outcrop on the left side of PA Route 82S.
	0.50	Stop sign. Turn right on Old Wagontown Road (Rock Run Road on maps) and cross the stone bridge.
	0.70	Overpass of US Route 30 Bypass.
	0.05	Mineral Springs road. [Future users of this guide should first obtain permission from Mrs. Steidler and pay a daily mineral collecting fee. The Steidler's home is located 0.3 miles west on the right side of Mineral Springs Road at the end of a steep black topped driveway].

	0.25	At the Y intersection, follow main road by bearing left. This is now Waterworks Road (figure 2).
17.50	0.10	Park on the grassy shoulder on the right side of Waterworks Road. Walk approximately 60 feet south along Waterworks Road to a T intersection. Turn right at the intersection and follow this road for approximately 60 feet to a gravel access road entering from the left. Follow the access road to the quarry. Normally, vehicles may be driven into the quarry.

STOP 1: STEIDLERS'S QUARRY

LOCATION: Wagontown quadrangle. This pegmatite is located 0.7 miles south of the village of Wagontown and just north of US Route 30 in Valley Township. The quarry operation was run by the late Frank Steidler primarily for beryl. He worked the quarry to its present size of three 5 foot benches.

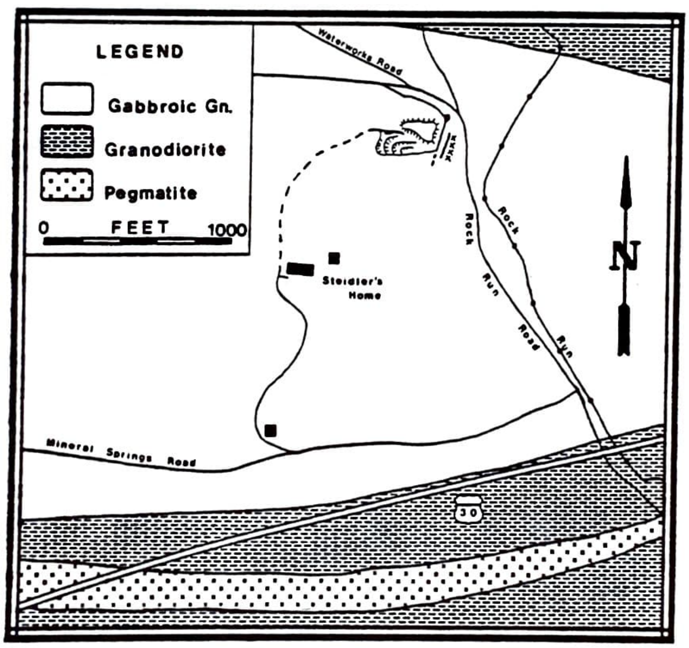

Figure 2. Generalized geologic map of Steidler's quarry. (Modified from Socolow, 1978).

MINERALS

Autunite: fluorescent.
Beryl: yellow to pale green hexagonal crystals up to 8" in diameter and terminated.
Columbite: rare, massive and euhedral.
Feldspar: as crystals on the old dumps.
Garnet: var. almandine (?).
Muscovite: common as books in quartz.
Opal: var. Hyalite; fluorescent.
Phosphuranylite: patchy coatings of bright golden-yellow scales; fluorescent.
Pyrite: small crystals.
Pyrolusite: as dendrites on feldspar.
Quartz: vars. milky and smokey; the latter is sometimes gemmy.
Thorianite: black to brown irregular grains or cubic crystals.
Thorogummite: yellow-brown or gray to black alteration rims around thorianite.
Torbernite: green; looks like autunite but does not fluoresce.
Tourmaline: var. schorl (?).

GEOLOGY: Unlike those in the area to the north from Easton to Reading, the granite pegmatites in the Piedmont Province of Pennsylvania commonly contain beryl. In general, the Piedmont pegmatites occur in a band extending across southern Chester and Delaware Counties into Philadelphia. Although more common in the Wissahickon schist, the granite pegmatites of the Coatesville area intrude Precambrian gneisses. These pegmatites are pod shaped and exhibit crude zoning (Geyer, Smith, and Barnes, 1976). In addition to beryl, these pegmatites contain the mineral association: quartz (white, smokey, or amethyst), microcline, albite, oligoclase, almandite-spessartine garnet, tourmaline (schorlite), muscovite, biotite, apatite, columbite, molybdenite, pyrite, chalcopyrite, and uranium bearing minerals (Montgomery, 1969). The beryl at these localities is "frozen-in" or completely surrounded by matrix; no open cavities have been found. For this reason, Pennsylvania beryl crystals both in museums and personal collections have most likely been repaired (Montgomery, 1969).

EQUIPMENT: Heavy crack hammer, chisels, and pry bar. The quartz of this pegmatite demands the wearing of gloves and safety goggles. An ultraviolet light, used after dark or under a opaque sheet of plastic, will aid in collecting and identifying the fluorescent species.

COLLECTING: The dump piles surrounding the quarry provide as good collecting as in the actual cut. The almandine garnets are found in the soil at the southwest corner of the quarry.

17.50		Continue straight on Waterworks Road.
	0.70	Turn right on Red Mill Road.
	0.50	Turn right on PA Route 340E.
	1.60	Blinking light. Turn left on PA Route 82N.
	4.40	Light. Intersection of PA Route 82 and US Route 322. Continue straight on PA Route 82N.

	4.8Ø	Intersection of PA Route 82 and PA Route 345. Continue straight on PA Route 345N (Bulltown Road) leaving PA Route 82.
	Ø.95	Cross over the Pennsylvania Turnpike.
	Ø.85	Stop sign. Junction of PA Route 345 and PA Route 4Ø1. Continue straight on PA Route 345N.
	1.ØØ	Stop sign. Turn right on PA Route 23E.
	2.5Ø	Turn left on St. Peter's Road.
35.8Ø	1.ØØ	Turn right on gravel driveway and proceed to the parking area at the top of the hill.

STOP 2: FRENCH CREEK MINE

LOCATION: Pottstown quadrangle. The French Creek Mine and dumps can be found Ø.9 miles north of the the village of Knauertown in Warwick Township (figure 3). The French Creek Mine and dumps are owned by Mr. Peter Chonka. Permission must be obtained and a fee paid before collecting.

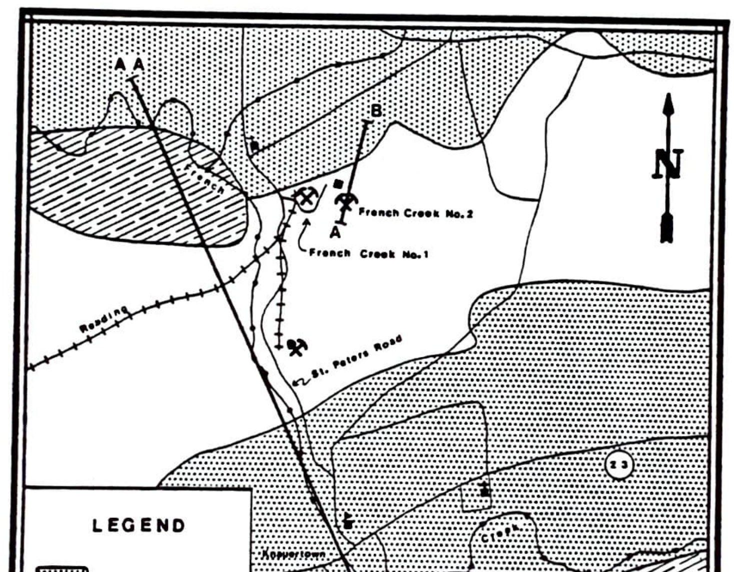

Figure 3. Geologic map of French Creek Mine. (Modified from Berg and Socolow, 1978).

HISTORY: The iron mines of northern Chester County, especially those in the villages of Warwick and Hopewell about 15 miles northeast of Valley Forge, played an important part in the Revolutionary War and are among the oldest in the nation (Smith, 1931). The French Creek locality lies between these two older mines on the same diabase dike (Smith, 1931). At French Creek, it was not until 1845 that iron ore was discovered and two open pits started on the Crossley Farm by Samuel Keim (Heyl, 1984). In 1850, a shaft known as the Elizabeth Copper Mine was excavated on the presumption that the orebody, with its abundant chalcopyrite, could be mined for copper (Smith, 1978). In 1854, at a depth of 145 feet, it closed without ever producing any copper (Smith, 1931). After a period of inactivity, the New York based French Creek Copper Company leased the property in 1863. Financial difficulties and transportation problems resulting from the Civil War caused this operation to go bankrupt (Evans, 1984). In 1866, the property and mining lease were sold to the prominent mineralogist and mine operator Charles M. Wheatley. Wheatley's Chemical Copper Company developed a new electrolytic process to extract copper from low grade ore. This technology, which is still in use today, allowed ore from the French Creek deposit to be economically processed for its copper content. Following Charles Wheatley's death in 1882, a joint venture between the E. & G. Brooke Iron and Steel Company and the Phoenix Iron Company began operations at French Creek for iron ore (Smith, 1931). In addition to expanding the Elizabeth Mine and renaming it the French Creek # 1, they excavated a second shaft (figure 4) known as the French Creek # 2

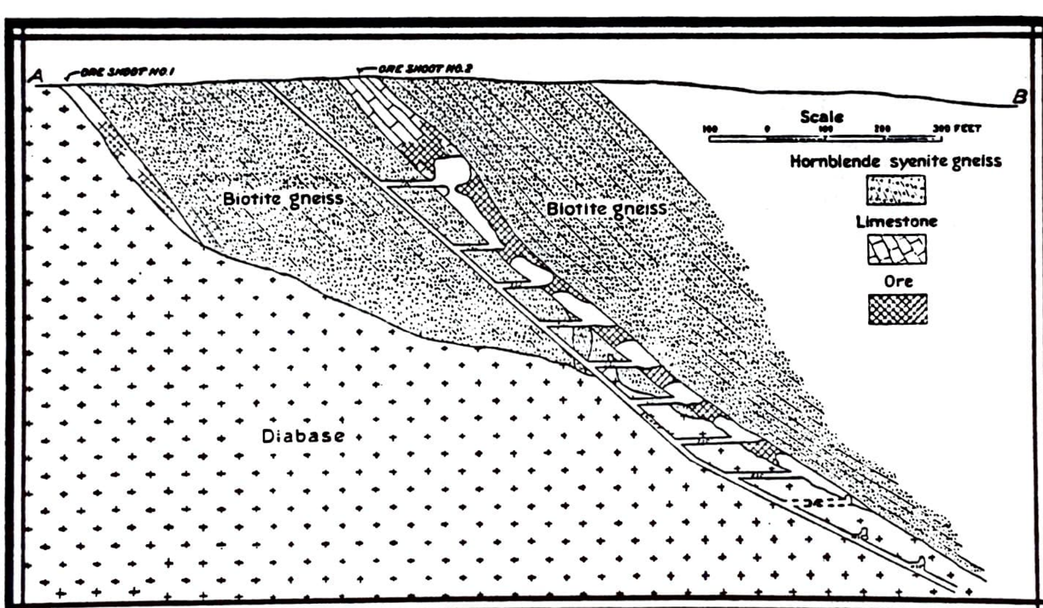

Figure 4. Geologic cross section of French Creek #2 Mine along line A-B in figure 3. (From Smith, 1931).

or Keim Mine (Heyl, 1984). Total ore production from the French Creek deposit is estimated at one million tons (Geyer, Smith and Barnes, 1976). Although the ore was essentially mined out in 1926, the mine was not closed until 1928. Finally the company sold the 22 acre plot to Peter S. Chonka who has made the mine office his home.

MINERALS*

Actinolite: var. byssolite; as fibrous mats; also needle-like inclusions in calcite.
Anthophyllite: fibrous.
Apophyllite: white tabular crystals lining fractures in the gneiss.
Aragonite: small crystals.
Augite: rare; associated with hornblende.
Azurite: rare; generally as a blue coating.
Biotite: in the gneiss.
Bornite: as a tarnish on chalcopyrite, pyrite and pyrrhotite.
Calcite: white and green to nearly black crystals and cleavage fragments; sometimes pinkish from oxidized iron.
Chalcopyrite: crystals; tetrahedrons up to 1/2 inch.
Chlorite: species unknown; crystal flakes.
Chrysocolla: rare; dull blue-green botryoidal crusts.
Cobaltite: silver-gray octahedrons, gray to pale brassy yellow crusts on pyrite octahedrons; usually coated with erythrite.
Datolite: small, glassy, white crystals with feldspar, apophyllite, and stilpnomelane.
Diopside: small, greenish blobs in the marble.
Epidote: massive; crystals rare.
Erythrite: rare; pinkish-lilac coating.
Garnet: var. andradite & grossular; small crystals.
Graphite: flakes in marble.
Gypsum: var. selenite; rare; small clear cleavage fragments and crystal groups.
Hematite: plates, frequently in calcite.
Heulandite: rare; crystals.
Hornblende: black blades.
Illmenite: black with good cleavage in diabase.
Jarosite: yellow-brown coating with gypsum.
Magnetite: platy, octahedral crystals and massive.
Malachite: coatings associated with chalcopyrite.
Microcline: pink.
Orthoclase: massive; flesh colored.
Pyrite: octahedral crystals and cubes.
Pyrrhotite: rare.
Quartz: massive and small crystals.
Scapolite: rare; species unknown.
Siderite: reported (?).
Sphalerite: rare; small, dark-brown crystals.
Stilbite: rare; crystal sheaves.
Stilpnomelane: small brassy-brown flakes in cavities with byssolite and feldspar.
Talc: flaky to massive.

Thomsonite: rare.
Tourmaline: var. schorl.
Zoisite: may be clinozoisite (?).

*(Geyer, Smith, and Barnes, 1976)

GEOLOGY: In the region around French Creek, the Precambrian gneisses of the Honey Brook Upland contain lenses of coarsely crystalline Franklin Limestone. This marble is diopside and graphite bearing. The basement rocks are overlain by red sandstones and shales of the Newark Basin and intruded along foliation by diabase dikes associated with the Triassic rifting event. The magnetite ore body at French Creek is the result of replacement of marble along its contact with the diabase. Breccia along the northern diabase contact has undergone contact metamorphism suggesting it resulted from the force of intrusion and not later faulting. The southern contact, on the other hand, is a post intrusion fault that exhibits 200 feet of displacement (Smith, 1931). Figure 5, based on exposures along the North Branch of French Creek, summarizes these relationships. Paragenesis of the deposit has been determined to be:

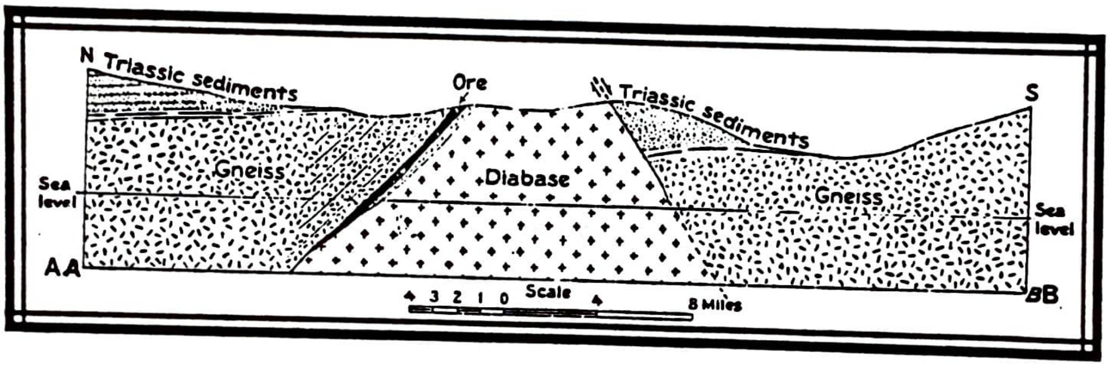

Figure 5. Geologic cross section of the diabase dike at St. Peter's Village along line AA-BB on figure 3. (From Smith, 1931).

garnet and augite; actinolite; epidote; chlorite, talc and some pyrite; magnetite; pyrite; chalcopyrite. An interesting feature of this deposit is the micaceous magnetite formed by recrystalization along cleavage planes in massive calcite (Smith, 1931).

EQUIPMENT: Rock hammer and chisels.

COLLECTING: Magnetite occurs with rhombic dodecahedral faces and chalcopyrite in tetrahedrons when crystalized in contact with calcite. Therefore, these crystals may be recovered from the matrix with a weak solution of hydrochloric acid. The dumps are the only place where collecting is allowed, but they contain so much material that there is no need to collect anywhere else. Thanks to Mr. Chonka, collecting is excellent anywhere on the dumps as a result of his maintenance and yearly bulldozing of the piles.

35.80		Return to St. Peter's Road and turn left.
	1.00	Stop sign. Turn left on PA Route 23E.
	3.20	Turn left into the parking lot of Coventry Tea Room. LUNCH
40.00		From the parking lot, turn left on PA Route 23E.
	0.25	Light. Turn right on PA Route 100S.
	5.00	Blinking light. Turn left on PA Route 401E.
	4.40	Light. Turn left on PA Route 113N.
	0.60	Turn right on Horseshoe Trail Road.
	0.40	Turn right on dirt road at the top of the hill.
50.85	0.20	Road divides, park on right fork.

STOP 3: BENJAMIN FRANKLIN GRAPHITE MINE

LOCATION: Downingtown and Malvern quadrangles. The pits and processing plant are located in West Pikeland Township. This property is owned by Mr. Henry Jordan of Horseshoe Trail Road and permission must be sought before entering the property.

HISTORY: At this locality, graphite was first mined on the north side of Horseshoe Trail Road in a pit known as the Just Mine (figure 6). Operated by the Benjamin Franklin Graphite Co., the Just Mine produced graphite from

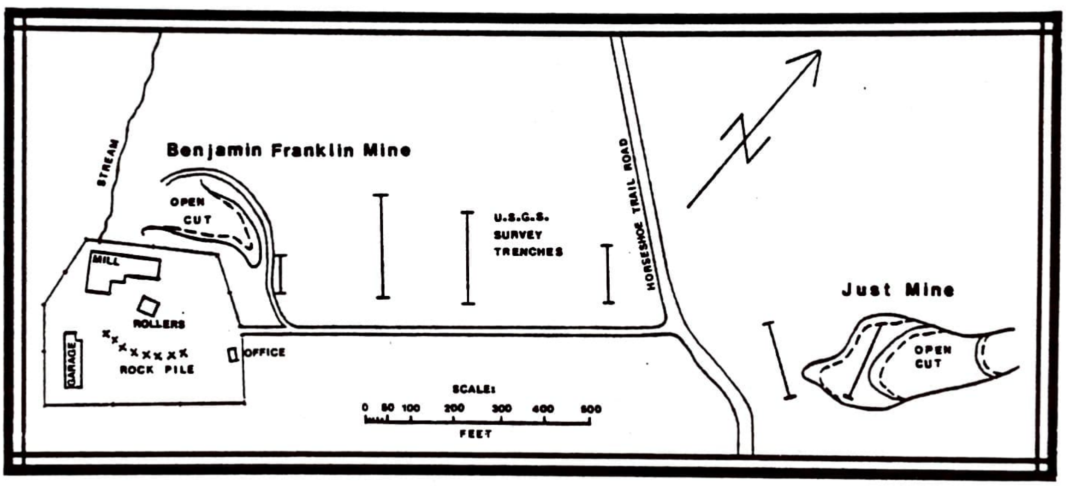

Figure 6. Map of the Benjamin Franklin Graphite locality. (Modified from Sanford and Lamb, 1949).

three benches in the Pickering Graphitic gneiss. Although described in 1949 as "the most important [deposit] in the state" by Robert Sanford and Frank Lamb of the U.S. Bureau of Mines, the graphite deposits in the

Pickering Creek Valley were only worked sporadically between the late 1870's and 1940. As a result of the curtailment in the supply of graphite during the Second World War, the United States Government bought 70.26 acres of land southwest and adjacent to the Just Mine. In 1942, the Benjamin Franklin Graphite Company leased this tract from the Defense Plant Corporation and built a complete mining and milling plant (Sanford & Lamb, 1949). In 1946, the Benjamin Franklin Mine and the Just Mine were leased to the North American Graphite Co. who, in renegotiating the lease, failed to make their payments. Mining stopped in January of 1947 and finally graphite production at the plant halted in April. A final attempt at production was conducted by Mr. Hess and Mr. Schmehl who subleased the grounds and plant, and worked a small cut next to the mill. The government finally terminated the lease to the North American Graphite Company in January, 1948. The plant was left in "stand-by condition" (Sanford & Lamb, 1949).

Graphite, known in the old literature as "plumbago" or "black lead," is infusible and unreactive with acids making it attractive for use in stove polish, foundry facing, metallic paints, lubricants, lead pencils, refractory crucibles for smelting steel, brass and bronze, and in electrodes and electric motor brushes (Miller, 1939). The Pickering Graphitic gneiss contains from 3% to 10% graphite. The material from the Benjamin Franklin Mine was sold for the manufacture of refractory crucibles. However, the fine grain size of the product proved inferior to coarser material (Sanford & Lamb, 1949). After the war when cheaper, large flake graphite from Madagascar was once again available, Chester County graphite could only be sold as a lower grade commodity (Miller, 1939). To economically compensate for this, the tailings from the rolling mills were refined and sold as construction sand (Sanford & Lamb, 1949).

MINERALS

Biotite: as flakes in the schist.
Garnet: small crystals.
Graphite: massive or as flakes 2-5 mm in size.
Hornblende: rare; in the gneiss.
Limonite: coatings and occasionally as pseudomorphs after pyrite.
Orthoclase: weathered grains in schist.
Pyrite: weathering to limonite.
Quartz: massive; blue and white.
Zircon: on rare occasions found in the schist.

GEOLOGY: The light to medium gray Precambrian Pickering gneiss contains graphite in three different styles of occurrence: as veins, in pegmatites, and as disseminated grains. At the Benjamin Franklin Mine, graphite occurs as disseminated flakes lying along schistosity. Flakes can also be found along the cleavage planes in feldspar (Geyer, Smith, and Barnes, 1976). When exposed to moisture for a relatively short time, the graphite bearing rock will weather and disintegrate (Geyer and Wilshusen, 1982). This weathering produces a distinctive soil stained brown to red by limonite and hematite and distinguishes the economically mineable deposit which extends for about eight miles from Kimberton to Byers.

EQUIPMENT: In addition to gloves and sturdy boots, all one needs is a light crack hammer.

COLLECTING: This locality has been the site of illegal dumping. Be careful of nails, broken glass, and the snakes that live there. The minerals of this locality were disseminated throughout the rock so that collecting in the dumps is as good as in the cuts. Due to the weathering properties of the gneiss it will be necessary to break open some of the boulders to get fresh material.

50.85		Return to Horseshoe Trail Road.
	0.20	Turn left on Horseshoe Trail Road.
	0.40	Turn right on route 113N.
	5.60	Turn right on Pot House Road.
	0.10	Stop sign. Continue straight.
	0.65	Light and railroad tracks. Continue straight.
	1.00	Light. Intersection with PA Route 29. Continue straight on Pot House Road.
	0.65	Stop sign. Turn right on South White Horse Road, crossing over Pickering Creek.
	0.55	Turn right, into the Pickering Valley Golf Course.
60.20	0.20	Park in the lot to your left on top of the hill.

STOP 4: BROOKDALE MINE

LOCATION: Malvern quadrangle. The Brookdale Mine is located just south of Pickering Creek in a ravine 1.5 miles south of Phoenixville, 0.4 miles west of White Horse Road and 0.7 miles southwest of Williams Corner (figure 7). Its precise location is marked by the smoke stack that still stands sentinel over the engine shaft. Permission to collect must be obtained at the office and a labeled mineral specimen left at the desk as token of thanks. The management requires that collectors stay off the greens and that excavated holes be filled before leaving.

HISTORY: Based on work by Evans (1984), prospecting for lead, copper and silver began in the Phoenixville area in the early 1680's . The real hey-day did not occur until after 1851, when the manager of two mines just to the north in Perkiomen sought financing from two friends and sank a mine shaft south of Phoenixville near Pickering Creek. The man was the famous Charles M. Wheatley, and the company formed was the Wheatley Mining Company. The next year in 1852, as many as a dozen individually owned mines were started on the south bank of Pickering Creek. Much of this activity was based on Charles Wheatley's interest in the area and his reputation in mineralogy. At this time he was running his own mine, managing the two in Perkiomen, and had a hand in starting and managing four new mining companies in the vicinity of his original shaft. Two of these new companies, the Brookdale and the Phoenix, sank shafts on the same northeast striking vein as the Wheatley mine, which by this time was known as the Wheatley Lode (Evans, 1984). In 1855, all three companies consolidated under the name of Pennsylvania Lead Company. In 1864, the New

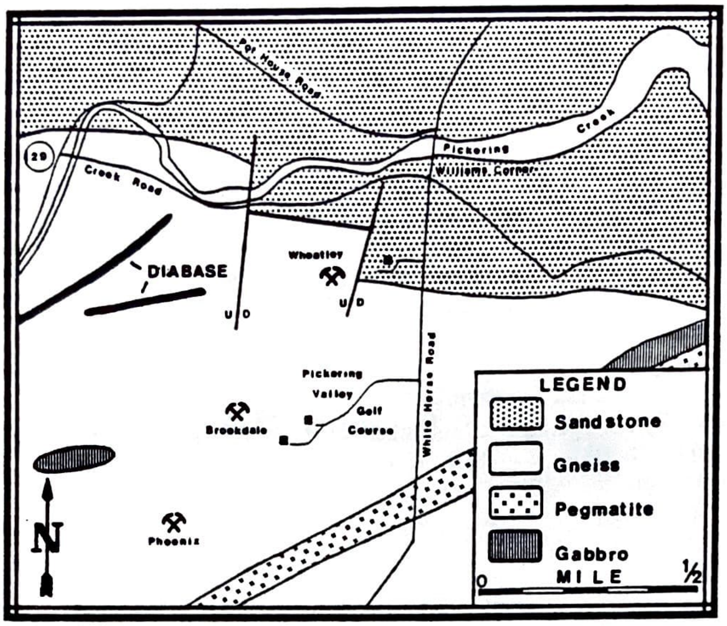

Figure 7. Geologic map of the Wheatley, Brookdale, and Phoenix Mines. (Modified from Socolow, 1978).

York and Boston Silver and Lead Company purchased all of Wheatley's holdings and made him superintendent of all their operations in the area. Production peaked about this time with the commencement of a considerable amount of excavation. In 1870, the same year Charles M. Wheatley became ill and was no longer able to work, the Wheatley, Brookdale and Phoenix mines shut down never to reopen (Evans, 1984).

MINERALS*

Anglesite: gray crystals on galena and quartz.
Ankerite: dark yellow to brown rhombohedrons.
Aragonite: tufts of small crystals.
Azurite: rare.
Barite: white masses in cleavage fragments.
Bornite: reported (?).
Brochantite: rare, deep emerald green crust.
Calcite: as cleavage fragments.
Cerussite: small crystals.
Chalcocite: reported (?); shiny black.
Chalcopyrite: massive in quartz and diabase.
Chlorite: species unknown; green balls on quartz.
Copper: rare; as wires.
Covellite: deep blue-black; when thin, brillant multicolored.
Cuprite: rare, red masses with malachite.
Descloizite: rare; reddish mammilary masses with pyromorphite.
Dolomite: tan ferroan variety found in veins.
Fluorite: rare; colorless crystals.
Galena: large cleavage fragments, often with anglesite or cerussite; tiny blebs in clear quartz crystals.

Gersdorffite: reported (?).
Goethite: with limonite.
Hematite: specular and micaceous.
Hemimorphite: uncommon microcrystals.
Hydrozincite: white coatings.
Limonite: coatings.
Linarite:(?) medium blue crystals with cerussite.
Malachite: small silky crystal tufts.
Mimetite: rare; tan hexagonal prisms and yellow tufts.
Pyrite: massive.
Pyromorphite: small, green hexagonal prisms coating quartz.
Quartz: milky; crystal clusters with single crystals up to 3 inches.
Silver: wires; extremely rare.
Sphalerite: golden-brown cleavage fragments up to 3 inches; uncommon as crystals on quartz.
Sulfur: rare; minute yellow crystals.
Tenorite: dull black cuprous oxide.
Vanadinite: uncommon; brown hexagonal prisms.
Wulfenite: red-orange, tabular microcrystals on pyromorphite.

*(Geyer, Smith, and Barnes, 1976)

GEOLOGY: Emplacement of an igneous body produced two sets of faults and fractures in the Precambrian biotite-hornblende granitic gneiss in this area. These structures trend approximately N20E and N50E and dip steeply to the southeast (Montgomery, 1968). Overlying the gneiss and cut by the faults and joints are red siltstones of the Triassic Stockton Formation. Hydrothermal solutions emanating from the igneous body subsequently filled the brecciated zones with quartz and sulfide minerals (Montgomery, 1968). These Triassic or younger ore bearing quartz veins vary in thickness from a few inches to a few feet with the vein at the Brookdale shaft averaging 2 feet (Smith, 1977). Later, as weathering and erosion brought the ground surface nearer to the deposit, chemical alteration by ground water produced oxidation of the lead-zinc-iron sulfides forming secondary minerals (Montgomery, 1968). As described by Smith (1977), the paragenesis was ferroan dolomite and chalcopyrite; quartz (the earliest with chalcopyrite, the latest with galena); galena; sphalerite; and the supergene minerals [those formed by weathering of the deposit]-pyromorphite, anglesite, and cerussite. This yielded an ore body that was composed of sphalerite and galena in quartz at depth capped by a supergene enrichment zone near the surface. Because zinc is more mobile in the weathering environment, secondary zinc minerals are uncommon despite the fact that the veins originally contained more sphalerite than galena (Geyer, Smith, and Barnes, 1976). Lead, on the other hand, was immobile and precipitated as pyromorphite. It was so abundant that literally tons of crystals were smelted to recover the lead (Geyer, Smith, and Barnes, 1976). Once the supergene enrichment zone had been removed and mining focused on the primary ore deposit, galena was the main ore mineral. Not only was the galena argentiferous, containing silver in quantities up to 120 ounces per ton, but the large quantities of zinc present in the primary ore possessed no value at the time (Miller, 1924).

EQUIPMENT: The weathered dumps require a shovel and/or hoe pick, garden claw and bucket. Rock hammer and chisel may be needed for trimming larger specimens.

COLLECTING: Collecting improves with depth in the dumps. Pyromorphite is green and so is vegetation, but a sharp eye will be able to find specimens lying on the surface.

60.20		Return to South White Horse Road.
	0.20	Turn left on South White Horse Road.
	0.40	Stop sign. Continue straight over the stone bridge.
	1.00	Turn right on PA Route 23E (Valley Forge Road).
	3.10	Light. Continue straight entering Valley Forge National Park.
	0.10	Follow PA Route 23E as it bears left.
	2.30	Light. Continue straight on Gulph Road leaving PA Route 23. The park information center is on your right.
	2.60	Light. Continue straight. Intersection of US Route 202 and Gulph Road.
	0.80	Light. Continue straight on Gulph Road. Valley Forge Memorial Gardens (Cemetery) is on your left.
	0.10	Turn left on Church Road, immediately after the cemetery.
71.70	0.90	Just before the light at the intersection of Church Road with Henderson Road pull into the loading dock area of a large blue building to your right and park.
	Walk	You are on the south side of the railroad tracks. With CAUTION proceed across Church Road and then across the railroad tracks to the north side. These are high speed passenger and freight lines, expedite crossing and do not dillydally on the tracks!

STOP 5: KING OF PRUSSIA QUARTZ LOCALITY

LOCATION: Norristown quadrangle. The outcrop lies approximately 1,000 feet west along the north side of the railroad tracks from the railroad crossing at Henderson Road (figure 8). This mineral locality is in an embankment cut by the Conrail right-of-way. The location is marked by the parking lot of the Ryder Truck Rental on top of the embankment filled with their yellow trucks.

MINERALS

Limonite: coatings.
Quartz: prisms of one sixteenth of an inch in diameter and up to one half inch in length lining small irregular vugs.

GEOLOGY: The Pensauken and Bridgeton Formations here are thoroughly weathered, cross bedded, clayey sandstones. These rocks are a remnant of an upland terrace that parallels the Delaware River (Geyer and Wilshusen, 1982). An increase in the pH at low temperatures enhances the solubility

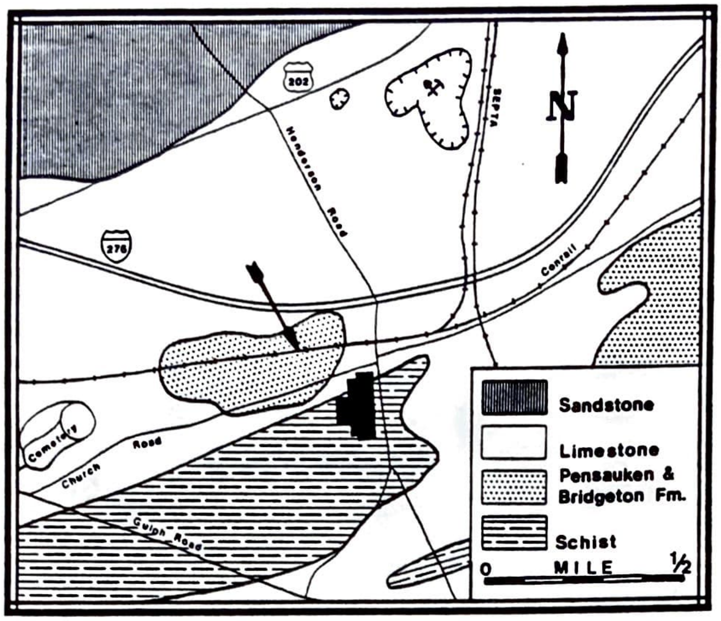

Figure 8. Geologic map of the King of Prussia quartz locality. (From Socolow, 1978).

of silica. A change in the pH of the groundwater as it moves through the sandstone results in local precipitation of quartz. This usually occurs in vugs where clear acicular authigenic quartz crystals are found.

EQUIPMENT: Shovel and/or hoe pick for digging and a rock hammer for trimming.

COLLECTING: After a good rain, the quartz crystals are commonly found on the surface. Digging into the bank will turn up blocks of coherent but weathered sandstone. When these are cracked open the treasure is revealed.

71.70		Turn left on Church Road.
	0.90	Stop sign. Turn right on North Gulph Road.
	0.10	Light. Continue straight on Gulph Road.
	0.80	Light. Turn left on US Route 202S.
	18.40	Light. Continue straight on US Route 202S.
	0.40	Exit for West Chester University. Exit and head north on Wilmington Pike.
93.00	0.70	Light. Intersection of Wilmington Pike and Rosedale Avenue. Turn left onto Rosedale Avenue to get to Shmucker Science Center or go straight to reach the town of West Chester.

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FOSSIL COLLECTING AT THE CHESAPEAKE - DELAWARE (C. & D.) CANAL

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The Chesapeake and Delaware Canal in northern Delaware is well known for its wide variety of Cretaceous fossils, especially Belemnites and Exogyra. The spoil banks created during dredging of the canal yield micro- to mega fossils from the local strata, these include: fossil teeth of sharks, skates, and rays as well as microvertebrate teeth; rare pterosaurian bones; trace fossils; various mulluscs and gastropods; and some echinoderms and brachiopods.

The stratigraphy of the section is generally Upper Cretaceous consisting of the Mount Laurel Formation which is underlain by the successively older Marshalltown, Englishtown, Merchantville and Magothy formations. At the base of the exposed section in this area are the variegated clays of the Lower Cretaceous Potomac Group.

The Lower Cretaceous stratigraphic sequence is composed of sediments almost entirely of fluvial origin including sands, gravels, and the aforementioned clays. A major cycle of sea-level rise which began at the end of the Lower Cretaceous lead to the influence of marine deposition at the base of the Upper Cretaceous, in this area the Magothy Formation. The origin of the overlying Upper Cretaceous section is linked to cycles of sea-level change and changing conditions of marine deposition.

PREVIOUS STUDIES

The Chesapeake and Delaware Canal, which links the Chesapeake Bay with the Delaware River, was first proposed in 1661 by Augustine Herman. Herman, a Dutch surveyer and map-maker, proposed to build a canal through the 14 miles which separated the two bodies of water. The idea was a sound one but it was not until 1804 that the Canal digging was begun. Work was discontinued in 1806 due to lack of funds. In 1823 the work was resumed and on October 17, 1829 the Canal was opened for business. The original Canal was 13 miles long, had a bottom width of 36 feet, a depth of 10 feet, and had four locks. Today the Canal is 13 miles long, is 450 feet wide, and 35 feet deep.

A fairly complete account of early geologic work at the Canal can be found in Delaware Geological Survey Bulletin 3 by Groot, Organist, and Richards (1954).

The first comprehensive attempt to describe and label the fossils from the Canal area was done by Richards et al. (1958, 1962). This report was published by the New Jersey Geological Survey and contained a systematic study of the Cretaceous invertebrate fossils of Delaware and New Jersey.

The decade of the sixties was the high water mark of Canal studies as the plant microfossils were studied by Groot and Penny (1960) and Gray and Groot (1966). This decade also saw the publication of Richards and Shapiro (1963) which served as the hand book for invertebrate identifications until it went out of print.

Owens et al. (1970) studied the lithology and fossils of the Upper Cretaceous of New Jersey, Delaware, and Maryland and in the same year Pickett (1970) remapped the stratigraphy of the Canal formations and reprinted the plates of previous publications in Delaware Report of Investigations No. 21 (1972).

In 1972 the U.S. Army Corps of Engineers published their own, Facts for Finding Fossils and planned to establish two permanent areas for the collection of fossils by amateurs. Unfortunately, this idea did not work out.

Selected papers on the geology of Delaware were presented to the Delaware Academy of Science in 1976 but were not edited for publication by Kraft and Carey until 1979.

The late 1970's saw, for the first time, an interest in the vertebrate remains of Delaware. Dinosaurs from New Jersey and Delaware were studied by Baird and Horner (1977), while Baird and Galton (1981) later identified pterosaurian bones collected from Merchantville spoils by dedicated amateurs.

The Delaware Mineralogical Society, in 1981, published a general guide by Lauginiger and Hartstein which included sketches of both vertebrates and invertebrates.

Gallagher (1982) and Hartstein (1985) continued the renewed interest in Delaware's vertebrate fossils by publishing articles in the newsletter of the Delaware Valley Paleontological Society. In 1983, Lauginiger and Hartstein wrote Delaware Geological Survey Open File Report #21 which was a detailed analysis of the fossil teeth of sharks, skates and rays. Lauginiger (1984) expanded the work with a report on the microvertebrate teeth found in a typical Marshalltown dredge site.

H. Allen Curran (1985) studied the trace fossils from the Englishtown Formation at the Deep Cut, and Pickett (1987) described the Canal stratigraphy for a Geological Society of America field guide.

ROAD LOG

Comments	Cumulative Mileage	Point to Point Mileage
Leave Schmucker Science Center	0.0	0.0
Turn right onto South Church St.	0.0	0.0
Follow South Church St. and turn left onto Rosedale Ave.	0.1	0.1
Follow Rosedale Ave. and turn right onto South High St.	0.3	0.2
Travel on South High St. until it becomes Route 202 South and then follow Route 202 South to I-95 South	14.7	14.4
Follow I-95 South and bear right onto Route 13 South	21.2	6.5
Bear left at traffic light and follow 13/301 South	24.7	3.5
Follow Route 13/301 South and then turn right onto Route 301/71 South	27.5	2.8
Follow route 301/71 South to a macadam road just past Lums Pond State Park	34.2	6.7
Turn left at the dead end and follow the switchbacks to the bottom Canal road	34.6	0.4
Turn left on the bottom road and follow to Site 1, The Deep Cut	35.0	0.4
Leave the Deep Cut and retrace route back to the macadam road	35.4	0.4
Turn right onto the macadam road and follow it to Route 301	35.8	0.4
Turn right onto Route 301 North	35.8	0.0
Follow Route 301 North to Howell School Road and turn right	38.1	2.3
Follow Howell School Road to stop sign and turn left	40.8	2.7
Turn right under the St. Georges Bridge and then left towards Route 13 North	40.9	0.1

Merge onto Route 13 North	41.0	0.1
Follow Route 13 North and turn right onto Cox Neck Road	41.3	0.3
Follow Cox Neck Road and turn right at traffic light onto Clinton St.	44.8	3.5
Bear to the right at Reedy Point Bridge approacb	45.1	0.3
Follow the road to dead end at the Canal and turn left	45.9	0.8
Bear left on dirt road at hill, park, and walk onto Site 2	46.0	0.1
Leave the site and return to Clinton St.	46.9	0.9
Turn left at traffic light onto Cox Neck Road	47.2	0.3
Follow Cox Neck Road and turn right onto Route 13 North	50.7	3.5
Follow Route 13 North and follow signs to I-95 North	61.3	10.6
Follow I-95 North and exit rigbt onto Route 202 North	67.8	6.5
Follow Route 202 North into West Chester where it becomes South High Street and turn left onto University Aue.	82.3	14.5
Follow University Ave. and turn left onto South Church St.	82.4	0.1
Follow South Church St. and turn right into Schmucker Science Center parking lot	82.5	0.1

LOCALITY #1

This locality is known as the Deep Cut and it is the only location along the banks of the Canal where the outcropping formations may be studied in detail. To the east is the Railroad Bridge and to the west is the Summit Bridge which carries U.S. Route 301 over the Canal.

At one time this area was an important fossil collecting locality but in 1982 the Corps of Engineers, in an effort to prevent erosion, built a stone dike along the front of the outcrop. This prevented the tidal waters from undercutting the outcrop but it also buried under tons of rocks and stones the sections of the Merchantville Formation whicb were producing important specimens. Only a public outcry stopped them from completely leveling the cliffs which had been declared a "Delaware Natural Area". Today, this area is only used for the study of the stratigraphic sequence of the canal. Occasional specimens can still be found along the beach at low tide but they are few and far between.

There are three formations which are exposed in this area, the one found at beach level is the Merchantville Formation. This formation is a dark gray to blue, micaceous, glauconitic, sandy silt which is very sticky when wet and contains a large invertebrate fauna. It is locally abundant in large ammonite and crab remains and was deposited in a fairly shallow, open marine area.

The middle formation is the light gray to white and reddish brown fine sands of the Englishtown Formation. This formation contains little glauconite and was most likely deposited in a nearshore, shallow water environment. It contains a large number of trace fossils which have been studied by Pickett _et al._ (1971) and Curran (1985).

The uppermost formation contains the massive, dark greenish-gray, highly glauconitic, fine silts and sands of the Marshalltown Formation. This formation marks the end of the transgressive-regressive-transgressive sequence which is exposed here at the Deep Cut. It is locally abundant in fossils.

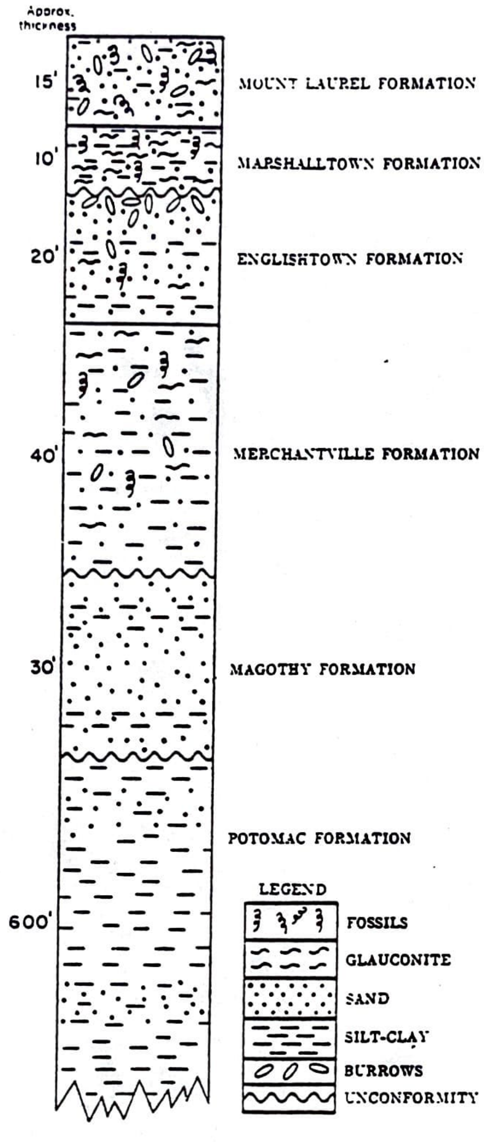
LOCALITY #2

This area is known as the Reedy Point North Spoil Bank and is located at the eastern end of the Canal where it enters into the Delaware Bay.

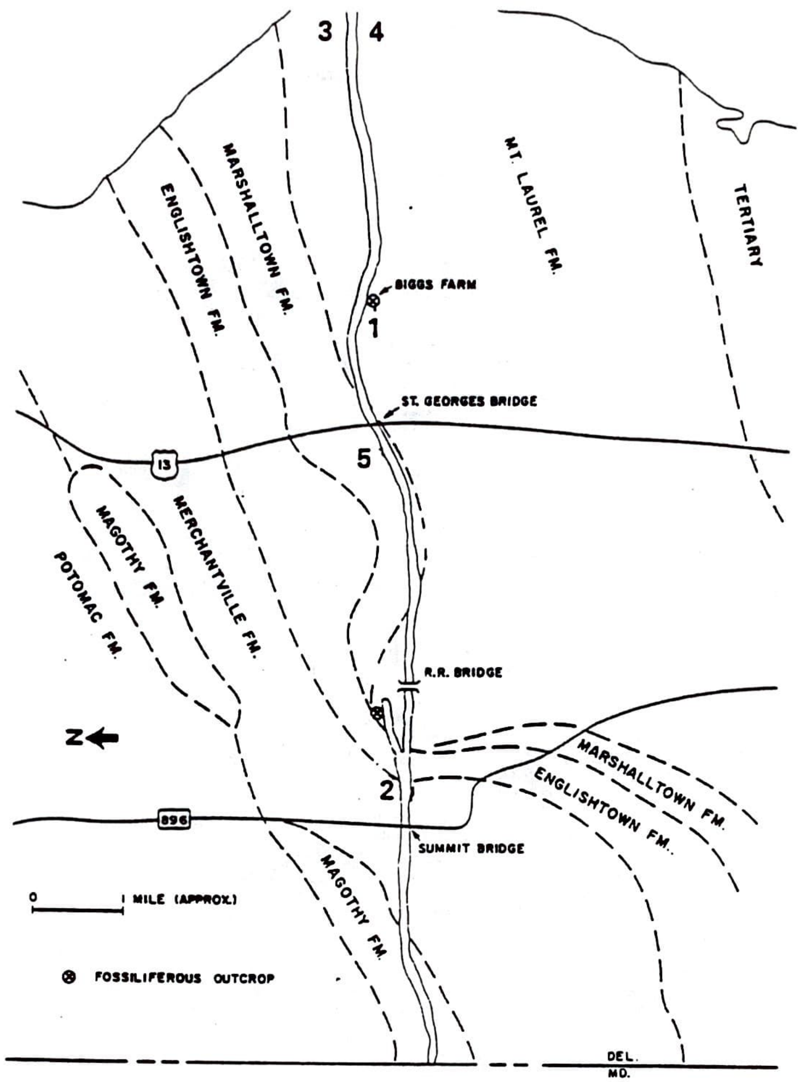
The Corps of Engineers, in an effort to keep the mouth free of silt and debris, must periodically dredge and remove material and deposit it on the sides of the Canal. This material is usually composed of estuary sands and the sediments from the highly fossiliferous Mount Laurel Formation.

The fossils are collected by walking or crawling along the spoil piles and picking them up. The more serious collectors use screens to sift the sediments in order to locate the smaller and rarer fossils.

Fossils from ten different phyla of animals may be collected here but the large shells of _Exogyra_ and _Pycnodonte_ and the broken internal skeletons of the squid-like _Belemnitella_ are the most common finds.

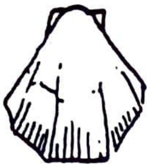


STRATIGRAPHIC COLUMN



GENERAL GEOLOGIC MAP OF C AND D CANAL

(1) Bigg's Farm
(2) Deep Cut
(3) Reedy Point North
(4) Reedy Point South
(5) St. Georges Spoils

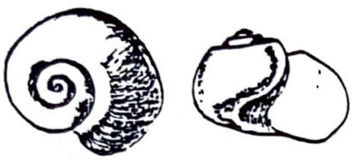


Neithea quinquecostata

Lima reticulata

Liopistha protexia

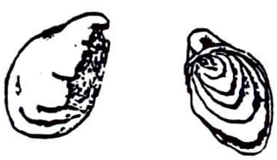
Nuculana pittensis



Gyrodes sp.

Margaritella pumila

Architectonicidae voragiformis



Gryphaeostera vomer

Calliomphalus americana

Haustater trilira

Laxispira sp.

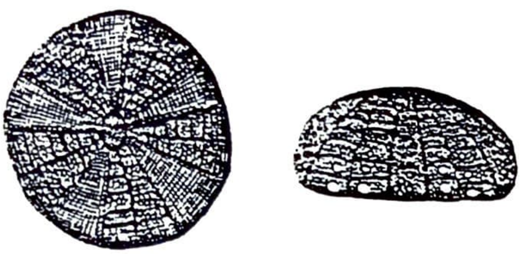
Cylichna recta

Eoacteon linteus

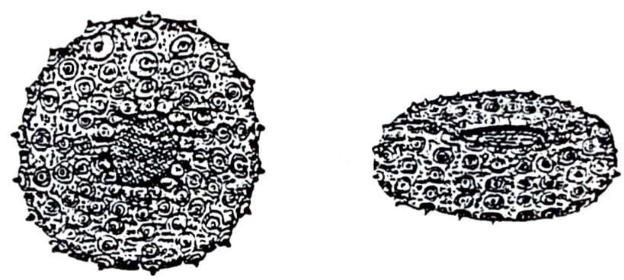
Opniomorpha nodosa

Spine

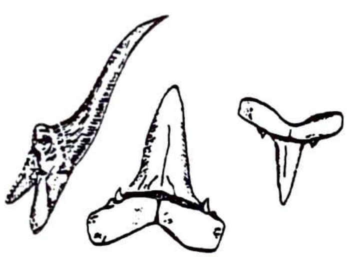
Plate



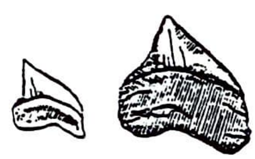
Boletechinus cf sp.



Phymosoma



Scapanorhynchus texanus



Squalicorax

Brachyrhizodus wichitaensis

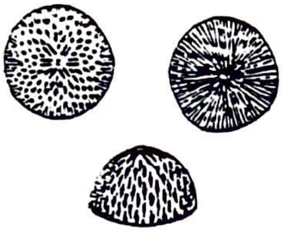
fish vertebra

Ischyrhiza mira

Odontaspis sp.

Enchodus sp.

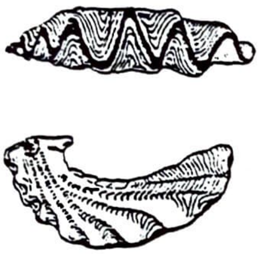
Mosasaur sp.



Micrabacia cribraria **Stephenson**

Terebratulina cooperi

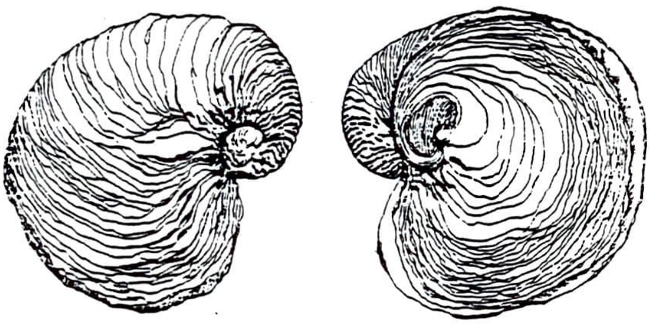
Frurionella cf sp.



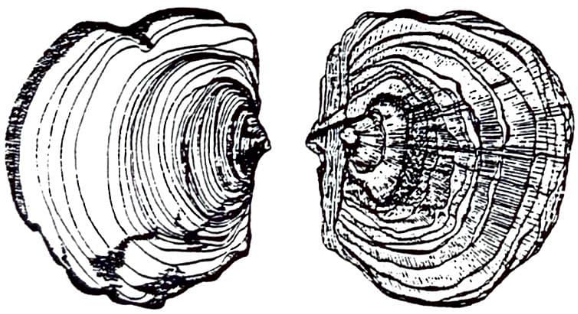
Ostrea falcata

Clavagella armata

Turritella



Exogyra cancellata



Pyncnodonte mutabilis

Belemnitella americana

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